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Simulating distortion and distortion circuits

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Using transformers in audio electronics

Make it with Micromite
Installing MMBASIC on a Raspberry Pi Pico

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SW
AM
FM
ON

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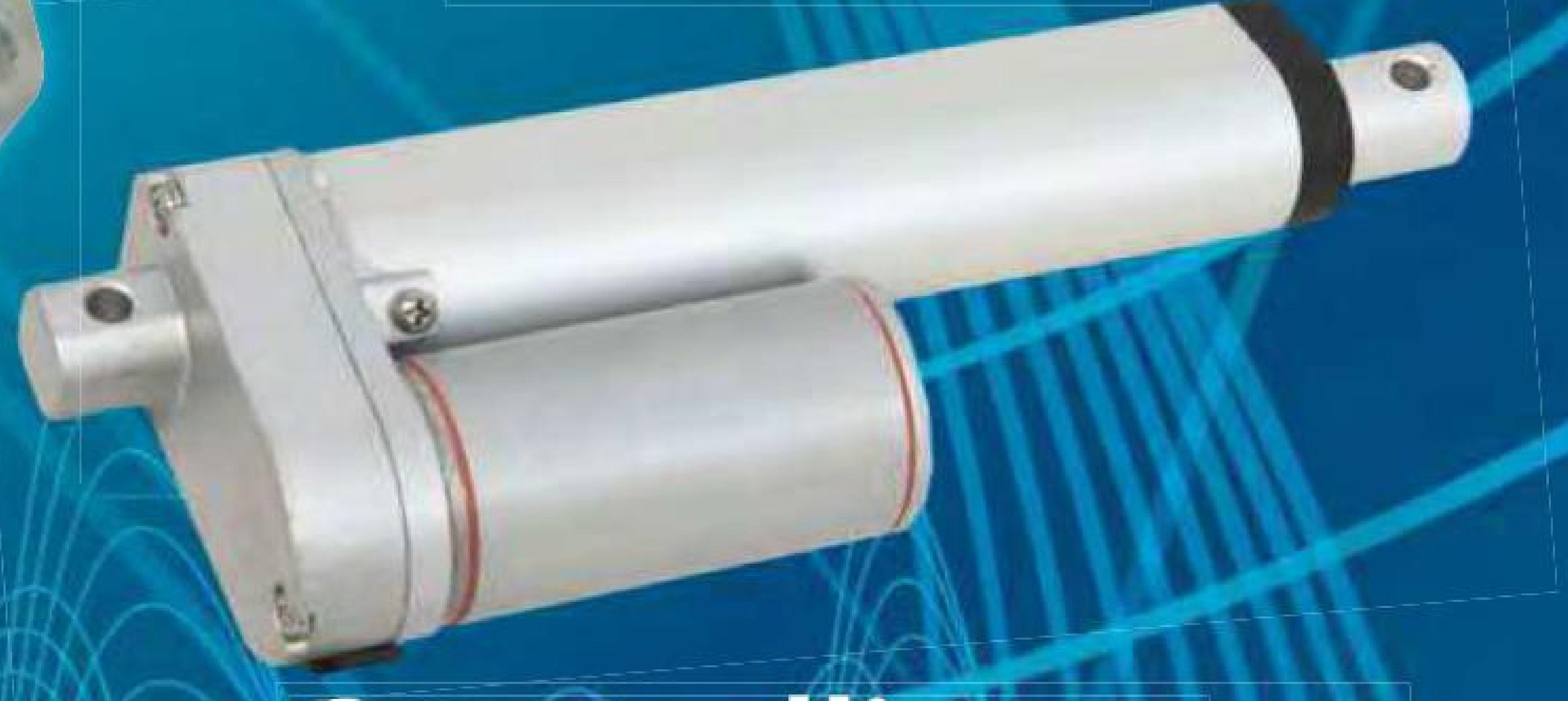

Single-Chip Silicon Labs FM/AM/SW Digital Radio Receiver

Controlling a linear actuator

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WAY
CROSSING

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EXIT

Toot toot! Model Railway Level Crossing with moving barriers, flashing lights and bell!

Advanced GPS Computer: construction and use

PLUS!

Techno Talk – Mixed Menu

Cool Beans – Choosing servos and a little competition

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Practical Electronics

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July 2022
ISSN 2632 573X

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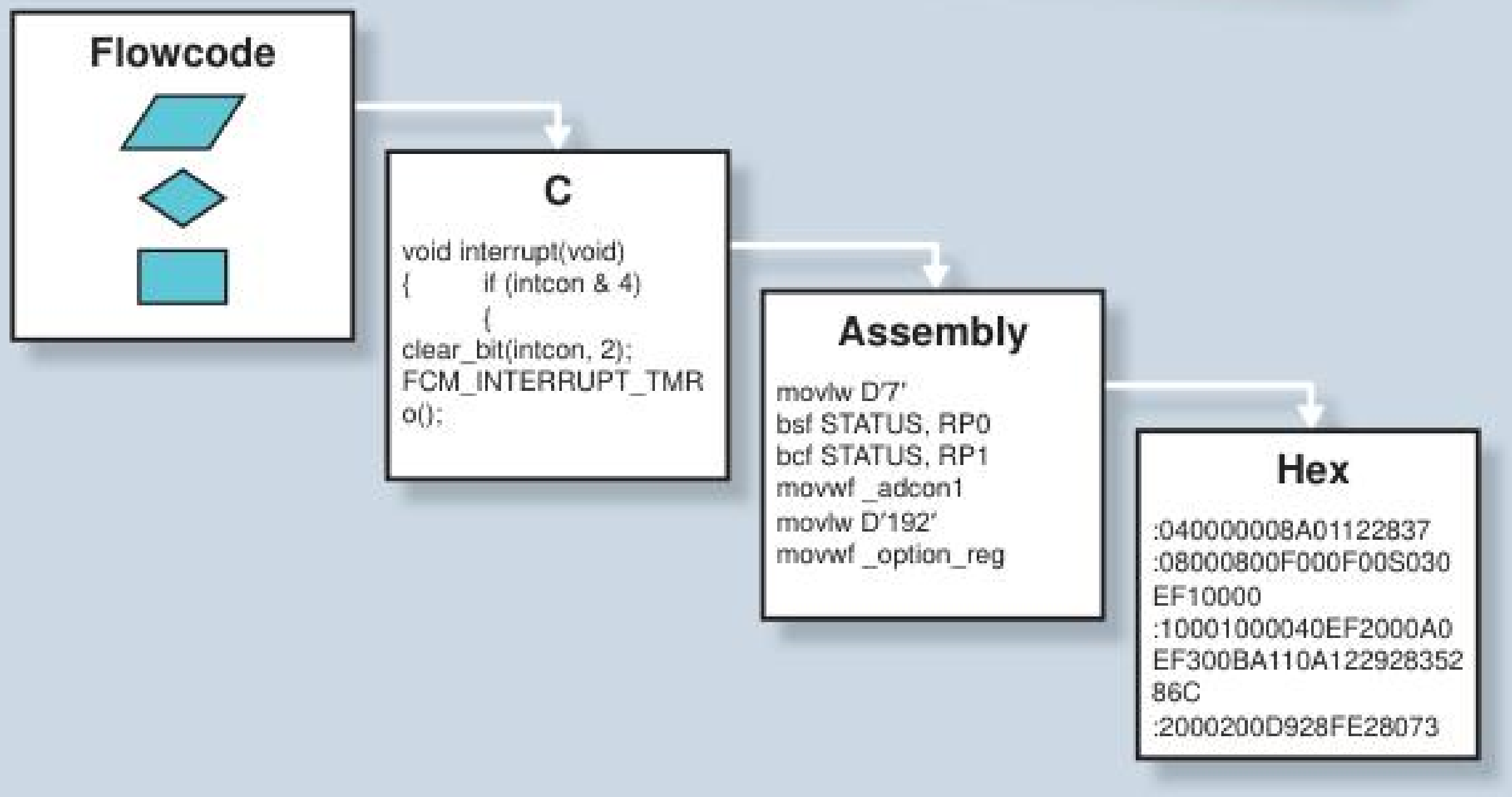
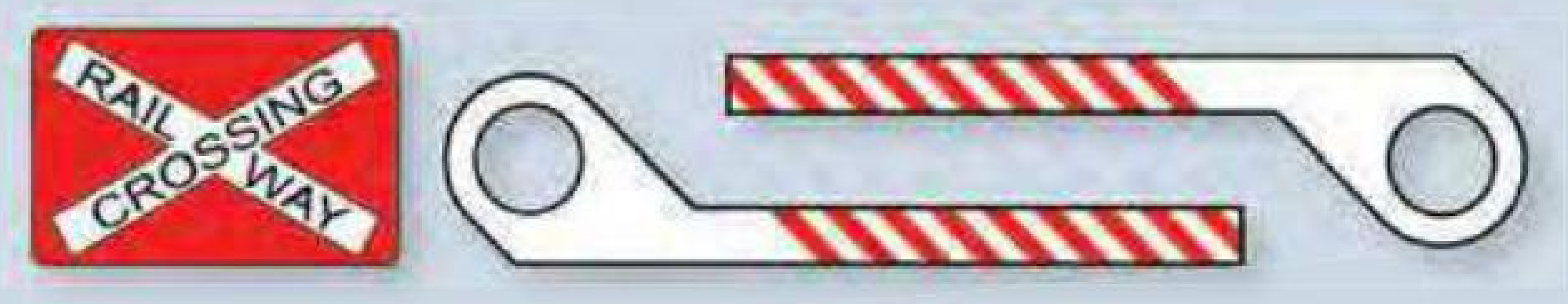


```
void interrupt(void)
{         if (intcon & 4)
          {
clear_bit(intcon, 2);
FCM_INTERRUPT_TMR
o();
```

```
movlw D'7'
bsf STATUS, RP0
bcf STATUS, RP1
movwf _adcon1
movlw D'192'
movwf _option_reg
```

```
:040000008A01122837
:08000800F000F00S030
EF10000
:10001000040EF2000A0
EF300BA110A122928352
86C
:2000200D928FE28073
```



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The August 2022 issue of *Practical Electronics* will be published on Thursday, 7 July 2022 – see page 72.

WIRELESS FOR THE WARRIOR

by LOUIS MEULSTEE

THE DEFINITIVE TECHNICAL HISTORY OF RADIO COMMUNICATION EQUIPMENT IN THE BRITISH ARMY

The *Wireless for the Warrior* books are a source of reference for the history and development of radio communication equipment used by the British Army from the very early days of wireless up to the 1960s.

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***Volume 1* and *Volume 2* cover transmitters and transceivers used between 1932-1948. An era that starts with positive steps taken to formulate and develop a new series of wireless sets that offered great improvements over obsolete World War I pattern equipment. The other end of this timeframe saw the introduction of VHF FM and hermetically sealed equipment.**

***Volume 3* covers army receivers from 1932 to the late 1960s. The book not only describes receivers specifically designed for the British Army, but also the Royal Navy and RAF. Also covered: special receivers, direction finding receivers, Canadian and Australian Army receivers, commercial receivers adopted by the Army, and Army Welfare broadcast receivers.**

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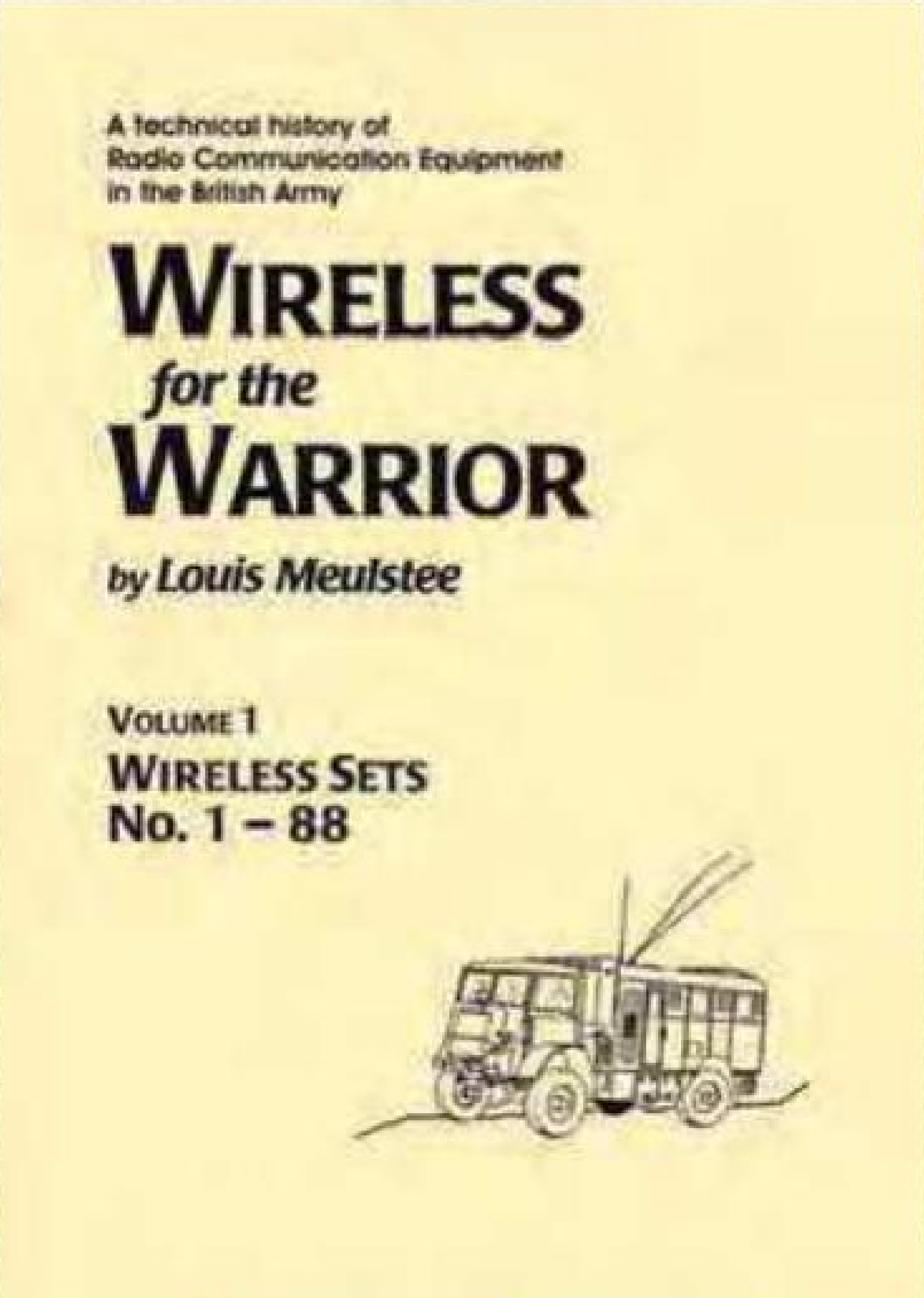

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WIRELESS for the WARRIOR
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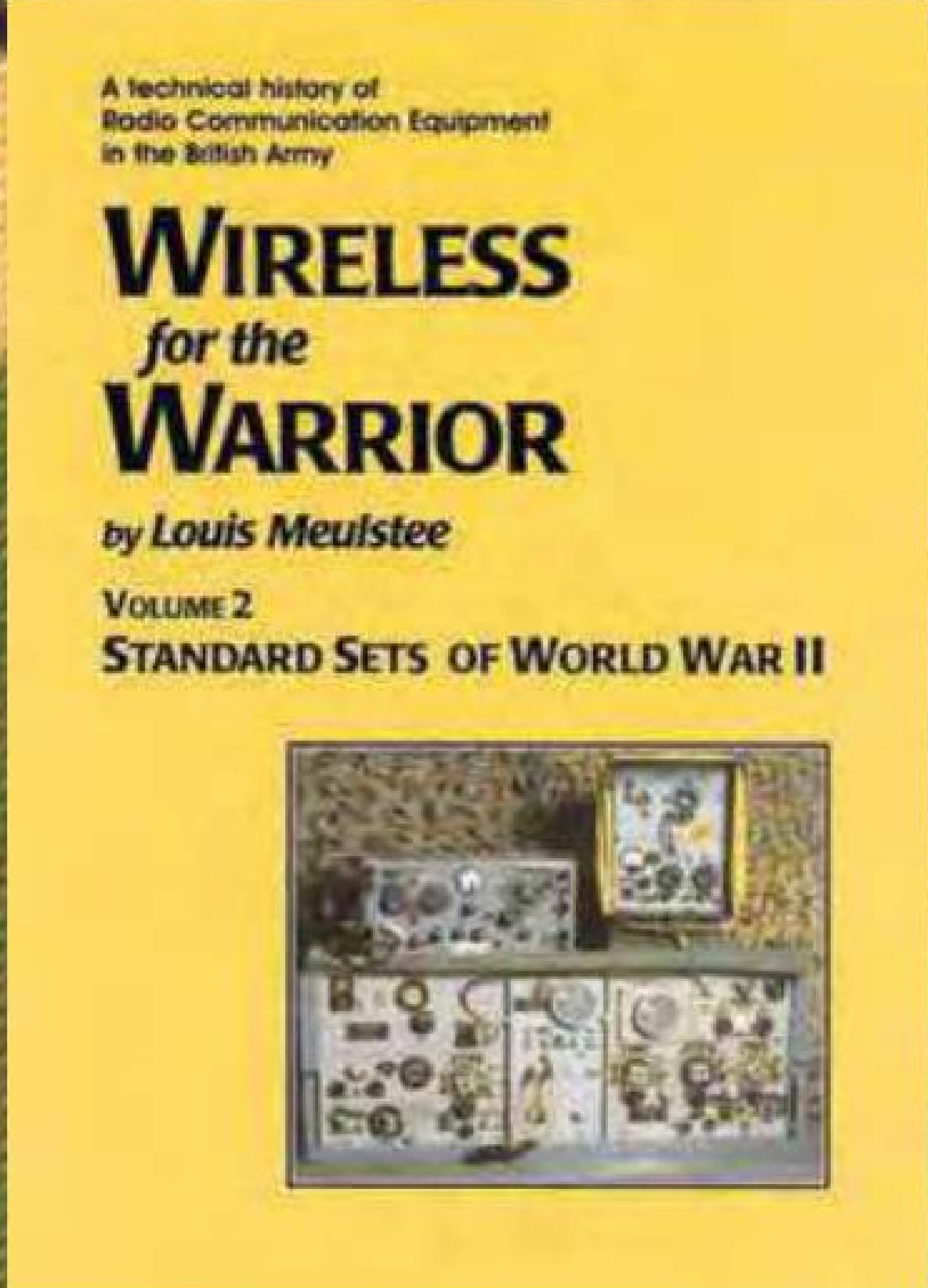
Wireless Sets
No. 1 – 88



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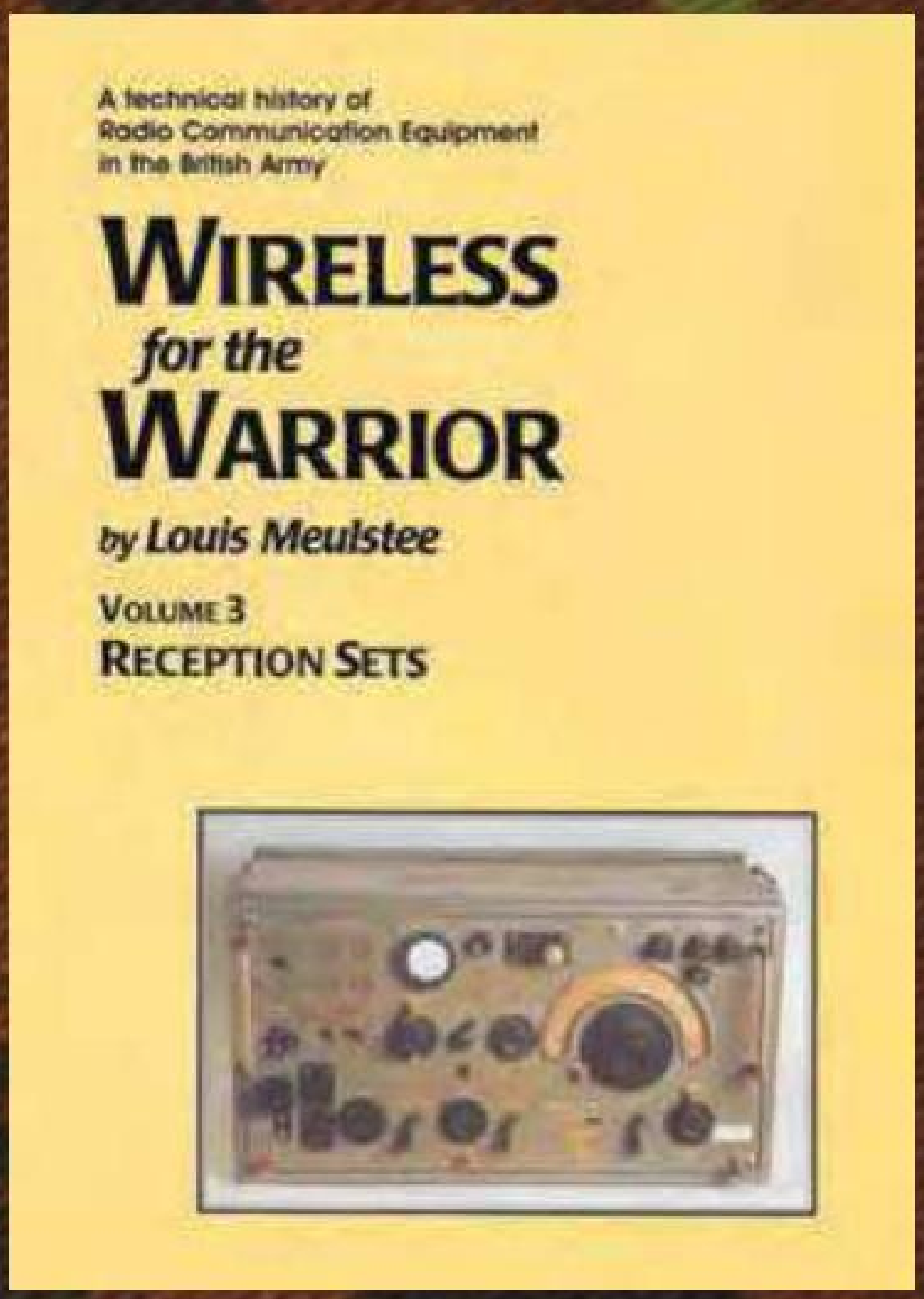
Standard Sets of World War II



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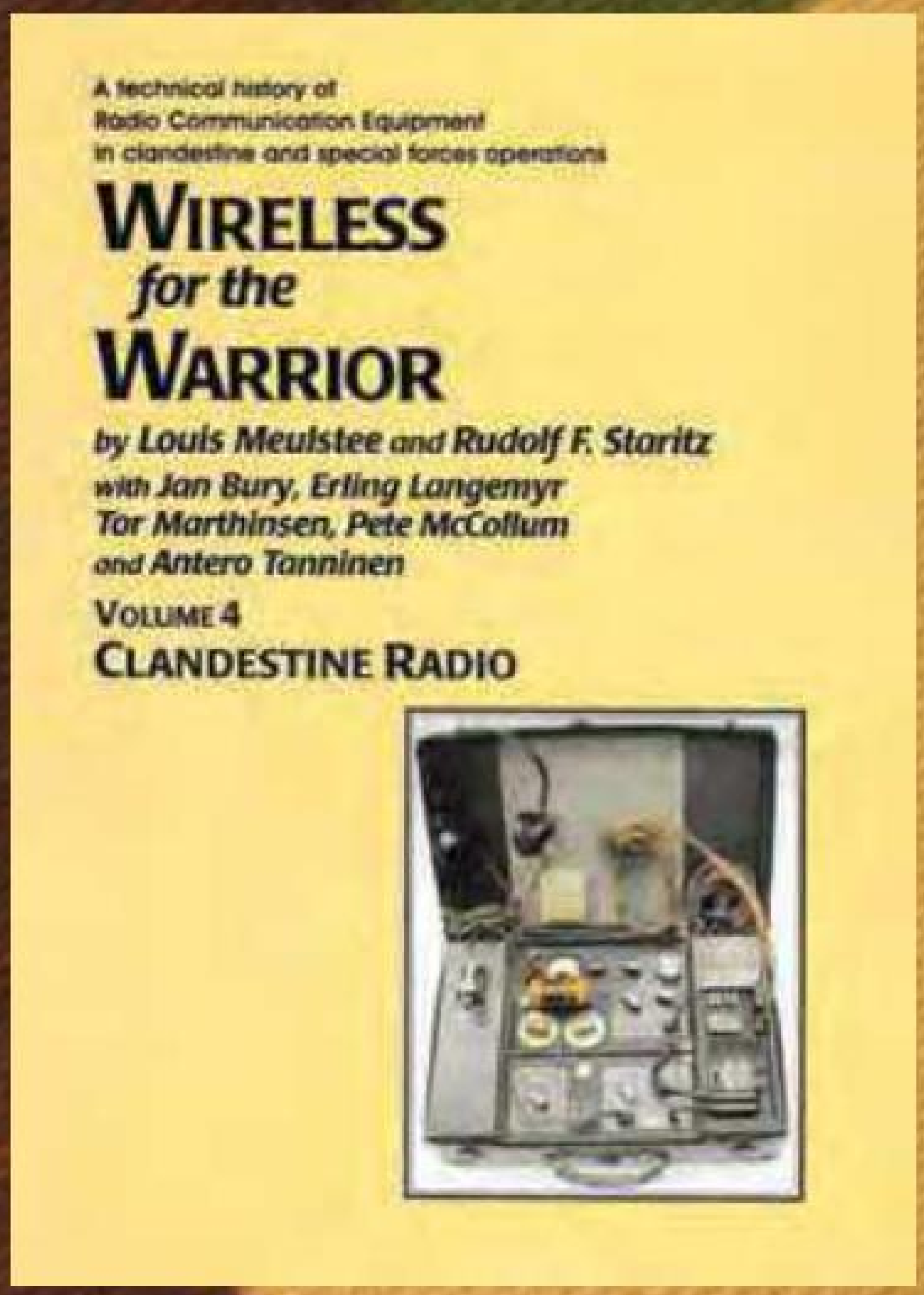

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in clandestine and special forces operations
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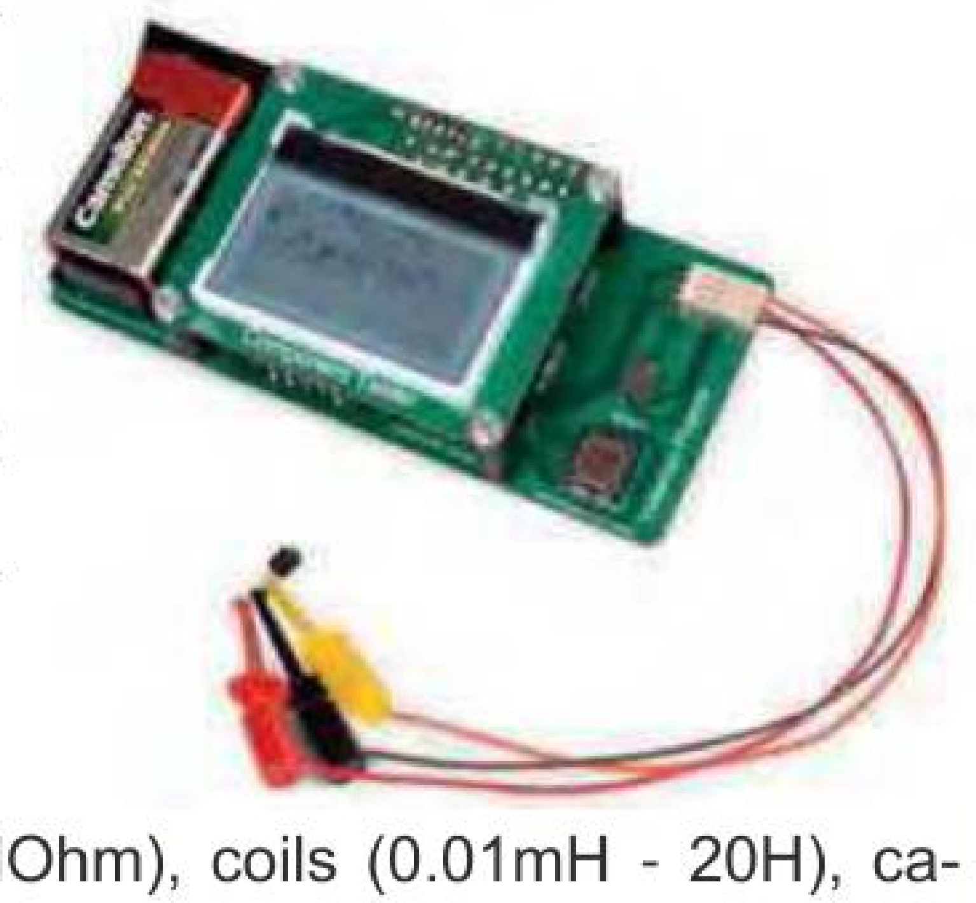

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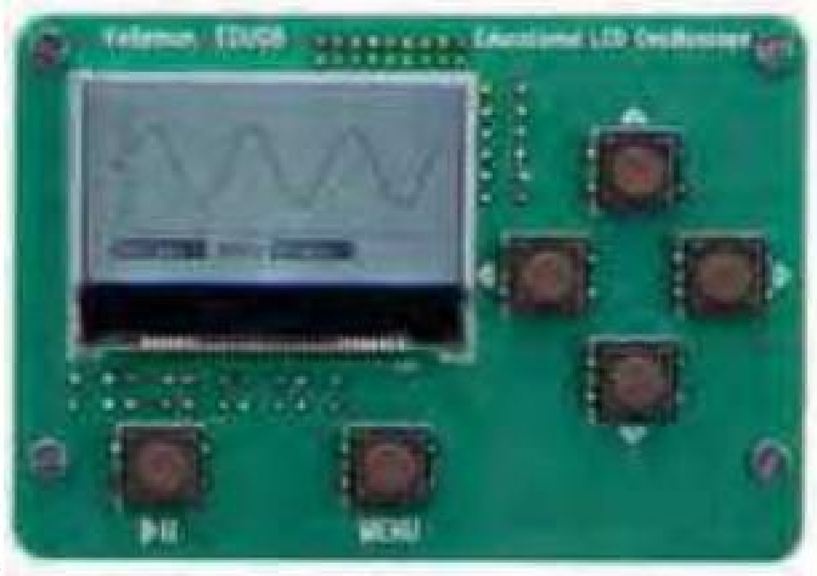

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A number of projects and circuits published in *Practical Electronics* employ voltages that can be lethal. You should not build, test, modify or renovate any item of mains-powered equipment unless you fully understand the safety aspects involved and you use an RCD (GFCI) adaptor.

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Editorial

The importance of repair

Last month's editorial about a well-known company deliberately making design and customer support decisions that render expensive products unnecessarily hard or expensive to fix obviously struck a chord with many of you. Thank you for the emails and advice sent in – all, much appreciated.

Several of you who took the time to write asked how we got to the point where almost everything electronic is now viewed as single use/disposable/unrepairable. It's an important question, but one that long-term readers of *PE* are in a good position to answer.

It boils down to a few key changes over the last few decades: the falling cost of parts and the rise of design complexity are at the heart of the success of the electronics industry and the challenge of repairability. Up until the recent silicon shortages – brought about by the pandemic and now the economic shock of war – the price of electronic parts followed an inexorable downward curve. At the same time, products became ever more complicated, bespoke and dense thanks to miniaturisation of not just microcontrollers, but every electronic component from passives to connectors. This makes goods cheaper and cheaper to produce, but conversely harder and harder to fix when they break down.

It was not always like this. Looking back to early issues of *PE* reminds us that parts and products used to be pricey. We regularly carried projects that encouraged readers to build radios, Hi-Fi and test equipment not just for the fun of it, but also because without a DIY approach, these products would be out of reach for many readers.

Likewise, repairability seemed to be built into the design ethos of companies. Jake Rothman's fascinating series on repairing the Leak Stereo 30 amplifier (see *PE*, Feb, May 2021) would be unimaginable for most modern Hi-Fi equipment.

On one level, it's good that products are cheaper and more accessible to those on modest incomes, but it's also produced such a voracious appetite for disposable items that the mountains of e-waste generated by endless consumption are degrading our environment.

Fortunately, it does not have to be like this. Recent moves by governments to force companies to make their products repairable are to be welcomed and we will watch developments with interest. Electronics giant Apple makes a lot of noise about their elimination of toxic chemicals, use of green energy and recycled aluminium, but the true test will be if they are prepared to sacrifice some profit so that their expensive products do not end up in landfill after a handful of years in operation.

Matt Pulzer
Publisher

Mixed menu

Techno Talk

Mark Nelson

This month, we have two tales that are as different as chalk and cheese, but they both mix biology and electronics. Let's tuck in…

The name London Underground probably suggests bustling tube trains running deep below the city's streets – but, of the network's 250 miles of track, a mere 21% are below ground in tunnels. The remaining 79% of the system is in open air at surface level, with – for most of the way – verdant greenery and all manner of wildlife on each side of the track. Much of this is highly desirable, but something very unwelcome has also colonised the green corridors: Japanese Knotweed. Fast-growing, highly invasive and almost impossible to eliminate, its vast root systems damage physical structures by undermining their foundations and drainage arrangements. Over time, it can even make them structurally unsound.

Boiling it alive

The highly regarded **www.ianvisits.co.uk** website reports that dealing with Japanese Knotweed is a serious issue for the Underground, simply because the common method of dealing with it – injecting glyphosate weedkiller into the plants – is labour-intensive and time-consuming. Often, it takes several years of repeated applications to fully kill the plants right down to the roots. Now the organisation is trialling an electrical method of successfully killing off these infestations instead of injecting them with chemicals. The Warwickshire company RootWave is the originator of this method, in which operatives use handheld 'electric wands' and a compact mobile generator to give the knotweed the kiss of death. The web report explains that waving the wand over plants applies a high-current shock that causes the water in them to boil, damaging the plant's cellular structure. This works both below and above ground level, with the damage done below ground that is critical in stopping the plant from regrowing.

Project manager Craig Ward reports: 'The plant dies instantly when we use RootWave Pro, halving the number of treatments we would expect to make with conventional methods.' He adds that using electric wands, two operatives can cover the same area as twelve people injecting glyphosate into the plants using the old method. The latter system also requires expensive specialist removal of the dead plants to a contaminated waste depot, whereas with RootWave the team leaves the plants to die on site and rot down naturally. You can watch a YouTube video of the process at: **https://youtu.be/6fvdB96i470**

Feeding hungry bacteria

Even tech-savvy readers of this article may be surprised to learn that as many as 40 different metals can be found within the complex structure of a printed circuit board; gold, copper as well as numerous rare earth materials, many of which are used in technology such as mobile phones. Some of these minerals are now in short supply, especially when they are mined in conflict zones. Recycling unwanted mobile phones and other tech is a no-brainer, but PCBs may need to travel thousands of miles to refineries for burning, with much of this valuable material lost and not recovered. But could these metals be recovered here in our own country, time after time and selectively by type? You bet they can!

Eat, don't heat

Geographical (the official magazine of the Royal Geographical Society) explains that the current techniques for recycling e-waste and electric vehicle batteries are known as pyrometallurgy and hydrometallurgy. Both processes involve searing temperatures with a high energy demand and deep carbon footprint, as well as toxic chemicals, all of which are harmful to the environment; consequently, the hunt is on for smarter solutions.

One that looks promising and is starting to enter commercial use is 'bioleaching', also known as 'bio-mining'. This involves covering an object in microbes to extract metals from e-waste using living organisms. Simply put, the bacteria munch on cast-off PCBs and other e-scrap. Several species of fungi can also be used for bioleaching. Bioleaching does not need high temperatures, but it does produce toxic substances, including sulphuric acid, that can damage the environment.

Commercial exploitation

N2S, based in the Suffolk cathedral town of Bury St Edmunds, is the firm leading the way with this exciting biotechnology. The company has been advocating and providing circular solutions for extending the life of technology for many years, but most recently it has collaborated with Coventry University to develop a way of harnessing the power of nature, using biotechnology to extract the valuable material within PCBs in an environmentally friendly way. The firm has also built a biotech laboratory where this new refining process will be developed.

The initial project, completed last autumn, has exceeded everyone's expectations. It has proved not only that the science can scale up to recover many more metals than originally planned, but N2S has also transformed into a biotechnology company, with new laboratories and staff trained to develop the technology further. For Coventry University it has also been hugely successful, leading to academic papers, new funding and PhDs as just some of the benefits. The university project leader has started a new career heading up the new bioleaching facility at N2S, after gaining technical and project management training, as well as graduating from the Knowledge Transfer Partnership's Innovation Strategy course.

Sebastien Farnaud, Professor in Enterprise and Innovation in Healthcare and Technologies at Coventry University summed up: 'We have developed an innovative, efficient and green solution targeting closed-loop systems, based on bioleaching technology to recover precious metals from e-waste. This technology has been embedded at N2S Ltd's premises, and has transformed their commercial capacities of IT waste management and revolutionised UK industry within the 'circular economy', while tackling environmental issues, and tightening security surrounding e-waste disposal.

He continued, 'This is a unique collaboration between a life science laboratory and a recycling company, which developed successfully a unique, novel approach to recovering metals from e-waste.'

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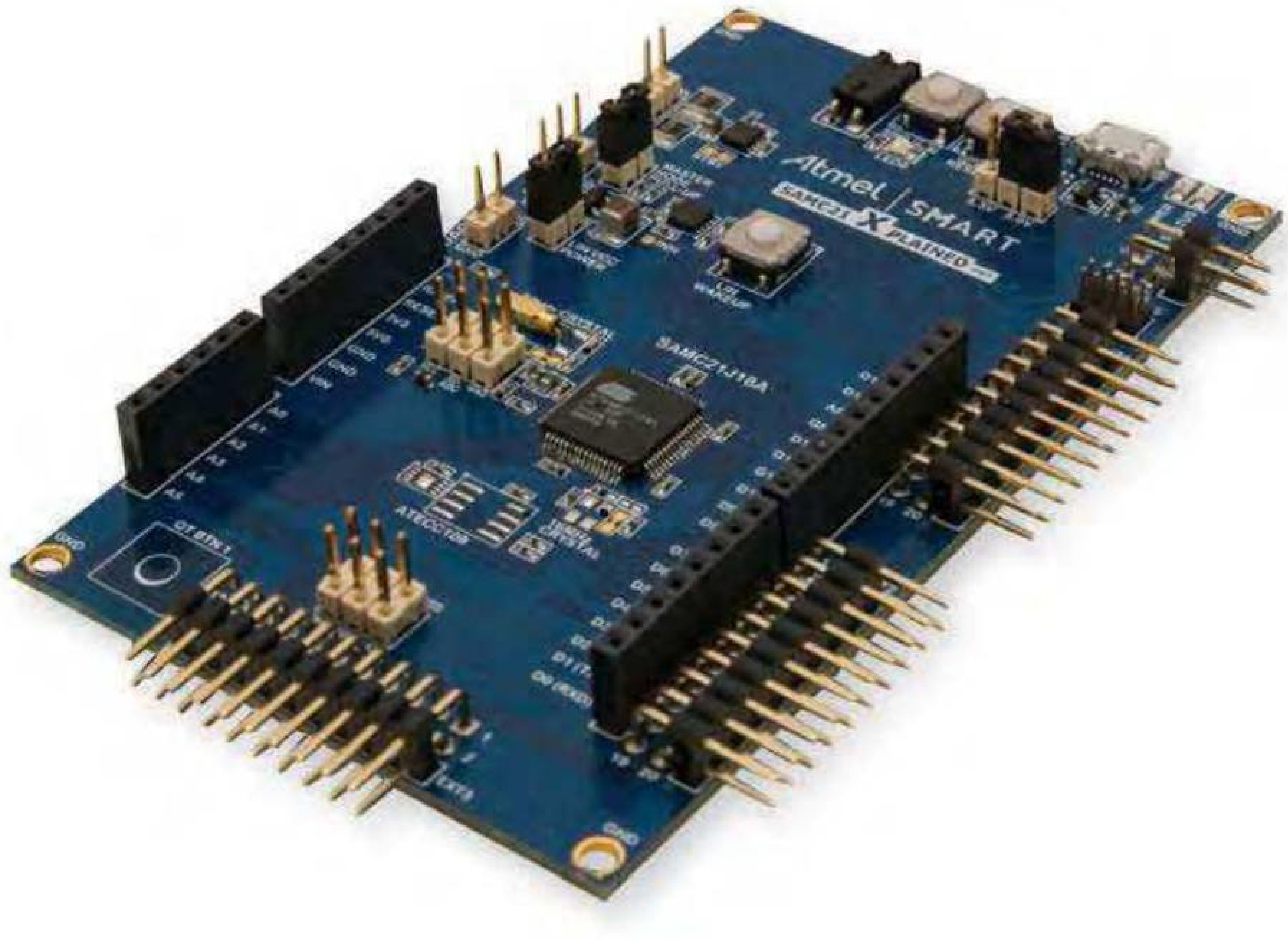

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Real vs virtual events – the good, the bad and the tough

If more proof were needed that Zoom-style online conferencing is no substitute for a live event, the DTG (Digital Television Group) Summit 2022 – Television Beyond Imagination – hosted on a real stage at Kings Place in London, offered it in spades.

Not just any old live event, of course. The speakers have to know their subject and not indulge in blatant product plugging, or run over time and spoil things for others who follow. Otherwise, the audience just buries their heads in mobiles, catches up on email or leaves the hall for a well-earned cup of tea.

Metaverse?

Despite a few niggles, the DTG was an object lesson in how to do it right. I had gone along with one main object in mind. To find out what people really mean when they talk about the Metaverse; and whether people who talk about the Metaverse really know what they mean by it.

David Sidebottom, principal analyst at Futuresource, says the figures show that 64% of everyone are 'aware of the Metaverse, but most do not know what it is'.

I would have liked to have passed on some of the other statistics which Futuresource offered, but the data was displayed as projected slides, with tiny text and graphics, camouflaged by light colour fonts on a white background that were largely illegible from halfway down the hall.

Likewise, although Prof Lucy Kueng, strategic advisor, senior fellow Reuters Institute, University of Oxford had useful things to say about the way the TV and streaming market is fragmenting, so that viewers find it increasingly hard to find what they want to watch, and then tame the tech needed to watch it, she too disguised her offering by using slides which were similarly illegible.

You'd think that tech and PR/comms gurus at a conference devoted to tech-based media could master Powerpoint in an audience-friendly way, but it seems there are still lessons to be learnt. Despite this, it was a useful and informative event.

Yet more streaming

Today's streaming giants like Netflix, Prime, Britbox and Mubi are battling for a finite pool of paying subscribers. There are more on the way – a service from Paramount will be bundled with Sky Cinema and via other routes as well. Speaking as someone with a cupboard full of streaming boxes and dongles (Roku, Now, Shield, Fire, YouView…) which are all able to get some streaming services but not others, I asked Dan Fahy senior VP in charge of streaming at Paramount UK, what I would needed to watch the new service on a big screen.

Fahy appeared surprisingly well informed for a sales boss and assured that all devices, including Amazon Fire sticks, but with the exception of Freesat receivers, would be able to pull in Paramount. The Freesat exclusion makes sense because Paramount is in bed with Sky, and the last thing Sky wants is to encourage punters to watch programmes for free with a Sky dish and Freesat box, instead of a Sky dish and Sky box.

Rufus Radcliffe, managing director ITV On Demand, fleshed out plans for a new ITV streaming service – curiously called ITVX – he needed to explain that it is not X-rated content!

Matthew Brooks, lead R&D engineer, BBC R&D talked intriguingly about the BBC's work on 'object-based media' which makes raw content easier to edit automatically, for instance to fit a TV programme to an available time slot. Everything relies on metadata, embedded in the content alongside picture and sound. You can play with some software tools here: **www.bbc.co.uk/makerbox**

Paul Nesbitt from kids' creator interactive community platform Twitch, Rhys Hancock of Metavision, Jo Redfern of 24 Watts, Robin Cramp from Production Park for XPLOR, John Cassy of Factory 42, and Zillah Watson, former Head of BBC VR and now a 'media & metaverse consultant', all had views on where the Metaverse is going, and what Gen Z undersixteens born into the age of streaming are doing with it. Some of the speakers fell into the trap of lumping together all young people of a similar age, when anyone who talks to teens knows they have hugely disparate behaviour patterns – some semi-permanently sequestered in warm dark rooms with screens and others out on a cold soccer pitch.

The consensus is probably best distilled down to the Metaverse is a mash-up of gaming, entertainment and education experienced with a variable mix of conventional TV screen viewing, virtual reality and augmented reality. While outdoor kids want to kick real footballs with trendy trainers, indoor kids want to create an alternative existence in a virtual environment with a personalised avatar wearing expensive virtual trainers.

No one talked about practical issues, like how people will handle real life in the real world without a VR headset. Several speakers agreed that young people want a 'low-friction' seamless experience with no need to download apps or submit to multiple sign ins. But so do older people – although they have learned the hard way that the Internet is thick with thieves, scammers and conmen waiting to pounce on any security short cut.

Virtual McAfee

A few days after the DTG event, McAfee, the computer security company that was taken over by Intel ten years ago in a tortuous string of deals, and which then went solo again earlier this year with more tortuous dealing, had little choice but to hold its 10th Annual 'Labs Day' as a virtual event, since its speakers from Holland, Dallas Texas, France, Germany and the UK were talking to journalists spread right across Europe.

I hope next year's event will be live again because the virtual gathering went on for far too long for virtuality (five painful hours with only a 15-minute break) and offered too little technical content. Real speakers in a real room would surely have sensed a loss of audience interest.

Nevertheless, it was good to be reminded that hackers are now hijacking PCs and using them to mine cryptocur-

Panasonic's latest Toughbook vitual promotion event was a textbook example of how not to organise invitations.

rency. The tell-tale signs are busy hard drives and racing fans when the PC should be idle; but the way Windows carries out housekeeping, such as indexing during idle hours can disguise a hijack. It's to be hoped that good protection against malware will block the intrusion, but I was left wanting to hear much more about how to do this.

I asked what McAfee thought about Microsoft/Windows Defender, the malware protection that comes free with Windows. It is, after all, in Microsoft's interests to stop its OS being over-run. But Microsoft is limited by trade laws in how hard it can promote free Defender against paid-for alternatives like McAfee or Norton.

McAfee's answer was predictably, politically vague, because McAfee bundles 30-day free trials of its own protection with new Windows PCs. 'We let people decide for themselves. But whereas Microsoft is thinking about a lot of things, we are only thinking about security,' said CTO Steve Grobman.

Grobman was more usefully forthcoming on the hidden security risks that come with Windows 11. 'The ability to run Android apps on Windows PC opens PCs up to mobile threats'. I wish he had given more detail.

However, Grobman did have a neat way to explain how artificial intelligence can try to pre-empt new 'zero day' malware, which no security software can be prepared for ahead of its first release into the wild. 'Photo indexing software will automatically label any picture with a dog in it. It doesn't know what your dog looks like, but it will still recognise any picture you take of your dog.' As another speaker reminded, there are only around half a dozen basic scams, which criminals are continually re-versioning, for snailmail, email, SMS texts and websites. So, AI can work the same way to spot new versions of old threats on zero day.

McAfee predicts that the ubiquitous Metaverse – whatever it turns out to be – will bring a whole new range of threats; like ransomware that threatens to burn down a user's virtual house.

A hard to attend Toughbook event

Panasonic has successfully carved out a nice niche for Toughbook laptops, which withstand rough treatment in pretty much all weathers. Usually, Panasonic launches the latest model Toughbook with hands-on press and trade demonstrations of what a Toughbook can take. Covid put these demos on hold, but even though Covid restrictions have now ended, someone inside Panasonic thought it would be a good idea to do the latest launch online rather than live.

Instead of Zoom or Teams, Panasonic used a conference system call 'Hopin'. I duly registered interest and received email confirmation of registration. After that I got several reminders, all from a Hopin NoReply email address, with click links to 'Add to Calendar' and finally 'Join Here'.

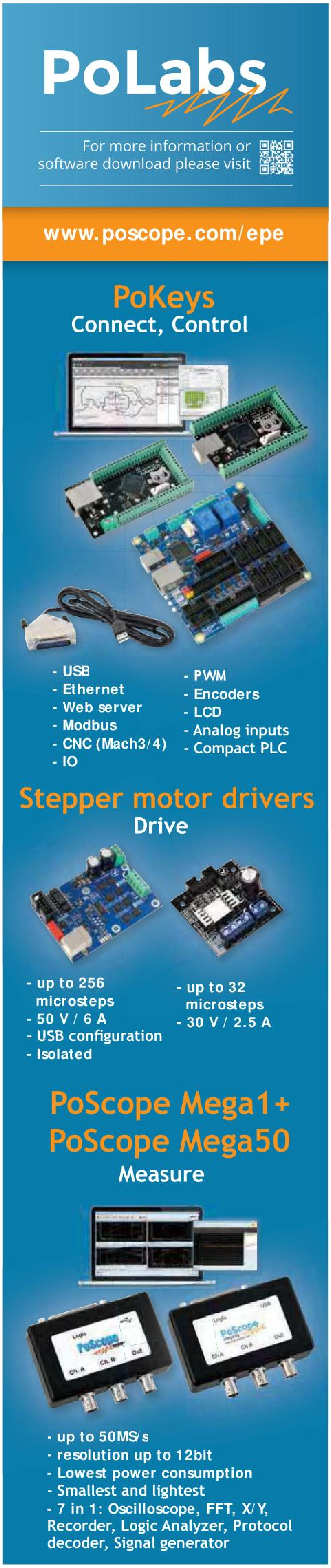
But when the time came to Join Here, clicking the link led to a Welcome Page which asked for a password. But no password had been sent.

What the Welcome Page should have said, but didn't, was what I found out by trial and error searching through all previous emails. The only click link that would gain direct access to the online conference was the authorised link in the original email, which was personalised. All the follow-up reminder emails were round-robins with no embedded authorisation. And all the emails were NoReply. I got online access to the event literally seconds before it ended.

I have now heard from another would-be attendee who hit exactly the same roadblock. Who knows how many others failed completely to join.

All it needed was for Hopin/Panasonic to send personalised reminders with authorised click links, or send a password, or include in the round-robin reminders the clear instruction to use only the original email for joining. How hard is that?

And why does it need a hack journalist to tell a leading computer company how to ensure that people can access the online event to which they have been invited? Even the toughest laptop is no use without its password.



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Net Work

Alan Winstanley

This month, we look at the rise of mobile payments and how Near-Field Communications (NFC) can automate some simple tasks. Plus, why electric buses might cause fireworks when least expected.

In the mid-1990s, the mobile phone ('cellphone' in North America) revolution was beckoning us from just over the horizon, and phone stores were starting to pop up like a rash – each one jostling to sign up customers to an expensive monthly contract (which is all there was). I was thrilled to get my hands on my first phone, a svelte Nokia 8110 'banana phone' sporting a sliding cover (a first for mobile phones at the time). A Nokia 6210 arrived a couple of years later, and its mono screen afforded rudimentary text-oriented 'web' browsing based on WAP, an unrewarding wireless web protocol that soon fell out of favour. Being able to order Nokia 6210 fascias – customised with your initials! – 'online' via WAP was a big deal at the time, and it was the precursor to the explosion in mobile e-Commerce that we see today. Phone upgrades followed inexorably, the writer adopting various HTC Android models along the way, and of course a whole chapter in telecomm history could be written about the role that Apple played in democratising/dominating cellphone ownership.

These days, a smartphone plays an almost indispensable part in our culture, whether as a social media device that owners simply can't live without; a useful tool that helps control networked appliances; an up-to-date map and navigation system; a way to cast programs to a TV screen; a camera to take snapshots of something before you take it to bits; or a wallet to pay for everyday purchases or store purchased tickets. (I'll highlight some neat contactless tricks later in this column.) There seems to be an app for every need: my plumber uses his phone as a spirit level and a flashlight. All major retail stores seem to have an app of their own, allowing them to stream their retail 'offer' straight into the palms of our hands.

NOKIA
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NOKIA

Nokia's 6131 NFC flip-phone, launched in 2007, was the first mobile phone to include NFC technology.

I'd like to teach the world to... Dial-a-Coke

The idea of consumers using a mobile phone – instead of hard cash – to buy things dates back over a quarter of a century. According to a blog post by the Australian point-of-sale equipment specialist Tyro (**https://bit.ly/pe-jul22-fin**), the foundations of 'cashless' mobile transactions first emerged in Finland back in 1997. Cellphones installed in Coca-Cola vending machines could 'phone home' when stocks of the sugary soda were running low, which would allow replenishment in a timely manner. Ultimately, the economics of this far-sighted idea didn't quite add up, but the cellphones were left in situ while engineers brainstormed other applications for them – including the concept of consumers using their *own* phones to connect to the machines and pay for a drink. Thus, the novel idea of a 'Dial-a-Coke' machine evolved.

By tapping a unique ID number into a phone, a vending machine would dispense a can and deduct the cost from the buyer's account seamlessly. It's said that the first ever user of mobile payments was a Finn who bought a can from a Dial-a-Coke machine at Helsinki airport in 1997. Soon, one third of all machine drinks sales were being made using mobile payments, and the revolutionary idea was then extended to car parking and vending machines in both Finland and Sweden.

As phones gained more powerful operating systems, colour touchscreens, cameras, GPS and Bluetooth, another technology would ultimately change the way we do things for ever: Near-Field Communications (NFC) offered device users the ability to 'tap' onto a 'contact-free' terminal to exchange data. In 2004, the Near-Field Communication Forum industry body was established by Nokia, Philips and Sony. The principles of Radio Frequency Identification (RFID) had taken shape many decades before 2004, the year that Nokia introduced the concept of an NFC-enabled phone that could read RFID tags. Their 'Field Force NFC Shell' contained an RFID scanner that clipped onto certain Nokia models. In 2005, a Microsoft blog reported that Nokia trialled a modified 6210 that could scan RFID tags and send an SMS message in response. Later, several other Nokia models offered a bespoke clip-on NFC shell.

According to the website *SecureID News*, in late 2005, NFC payments, parking and a tourism application were tested in early mobile phones in France using NFC-enabled Samsung D500s. (An interesting timeline is posted at: **https://bit.ly/pe-jul22-nfc1**). In 2007, Nokia launched the 6131 NFC flip-phone, the first mobile phone to include NFC technology. How Nokia envisioned users utilising their NFC phones for ticketing, contactless payments, swapping contacts, sharing documents and more is shown in a contemporary promo video at: **https://youtu.be/bxzt3Z3Rn84**. (Using NFC to share contact details this way reminded me of the lovely 1990s Handspring Visor PDA, which used infrared to exchange contacts with other users. In practice, nobody really bothered: we still swapped physical business cards!)

At the same time, UK network operator O2 gave 500 London commuters new Nokia NFC phones to play with, in an experiment that tested mobile payments for Barclays, or for travelling on London buses using an NFC phone as an Oyster payment card. After the event, there was little doubt that the convenience of using mobile, contactless payments instead of fumbling for cash or a debit card had won their users over. Strangely, Apple iPhones were

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A QR code appearing on a British TV advert for viewers to scan with their smartphone.

late to the game and only gained NFC in 2014 when the iPhone 6 and Apple's proprietary Apple Pay came along.

An ABC of NFC

TV program makers and advertisers know it's easy to scan a QR code, and they're now appearing on shows and ads, inviting viewers to scan them (if they're quick enough!) to learn more about what's on the screen. However, readers can also harness their phone's NFC technology to automate various tasks, by tapping NFC 'tags' or stickers that you can easily program yourself. Adhesive NFC labels, hanging tags and keycards incorporating RFID chips are commonly sold on eBay and low-cost NFC helper apps are available to program them.

NFC
NFC Sticker Tags
12 Stickers. 6 Colours.
Automate Your Life
NFC
Update mobile settings, launch apps and open webpages with a tap of your mobile phone.
Compatible with NFC Enabled Mobile Phones
Check your phone at rapidnfc.com/phones
RapidNFC

NFC stickers and tags are readily available online and can be used to automate tasks or operate smart home devices.

An NFC tag can do anything a QR code can, and a whole lot more. *Net Work* first covered the advent of both QR codes and NFC tags more than a decade ago, so these technologies are well established. For readers who want try out this technology, in the author's experience, later versions of Android (10+) apps offer more chance of success with NFC tags. (iOS NFC apps have not been tested by the author.)

Unfortunately, some useful NFC tasks such as swapping Wi-Fi networks have now been disabled, as Google now blocks Android developers from accessing some key features (eg, Wi-Fi settings). This has frustrated the author's plan to swap mobile Wi-Fi SSIDs with a tap, after settling at his desk in the home office.

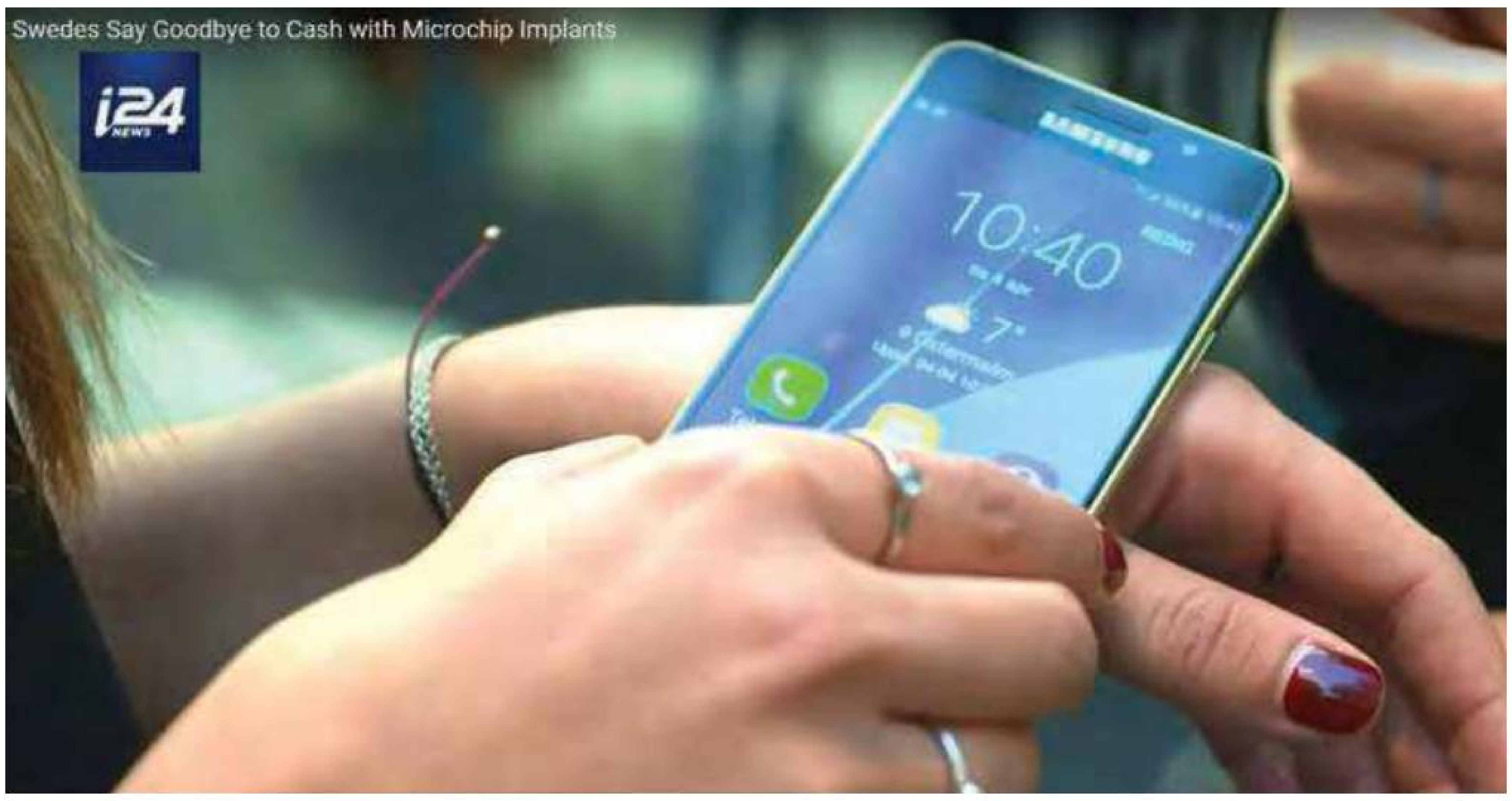
The NFC Tools and NFC Tasks apps for Android (both are needed – other apps are available) allow you to read, write and program tasks using compatible NFC tags. Ideas include toggling Bluetooth, managing phone call features (eg, toggle the speakerphone or hang up) or selecting Car mode once you get in the car. Alternatively, you could toggle the phone's flashlight, add a video link, compose a Tweet, start an email or send a text. A full feature list is in the NFC Tools 'Tasks' menu. Simply create a task then choose Write... to upload it onto the NFC tag via your phone. The technology can also interface with Alexa or Google Nest, allowing smart appliances to be controlled. In the author's case, the smartphone must be unlocked and running for NFC Tasks to work. Many more ideas are provided at: **https://bit.ly/pe-jul22-nfc2**

Android users can search for NFC Tools by Wakdev on Google Play Store. Since the apps and NFC tags are low in cost, using them to automate tasks requires very little investment and they're worth knowing about. The Pro version of NFC Tools unlocks more options.

Cashless is relentless

As many readers know, payment services like Google Pay or Apple Pay are now heavily integrated into NFC smartphones, and there is no doubt that touch-tapping a smartphone to pay for something has become a convenient and painless no-brainer. Google Pay increases security by masking your payment card number using its own number instead, so the seller never sees your actual card details. Store loyalty cards can be coupled into the system as well.

The flip-side of using contactless payments is the risk of us drifting into becoming a 'cashless society'. Sweden is endeavouring to do away with the need to carry Krone altogether, relying on mobile payments and cards instead. Like many countries, Swedes are paying less often in cash. Even public toilets demand contactless payments or cards: cash is not accepted when 'spending a penny', as Brits call visiting the bathroom. According to Sweden's Riksbank, 'In ten years, the proportion paying with cash has fallen from around 40% to less than 10%, and the 'Swish' [Swedish mobile] digital money system, alongside Apple Pay and Google Pay are highly popular – cash is now mostly used for small payments and primarily by older people'. Thousands of Swedes have even shunned the handling of germ-laden cash or cards altogether in favour of having tiny microchips, no larger than a grain of rice, planted under their skin.


Swedes Say Goodbye to Cash with Microchip Implants
i24 NEWS
10:40

In Sweden, a shopper offers contact details in an implanted microchip using a smartphone. (Image: i24NEWS/ YouTube).

CAVForth
autonomous bus
Stagecoach
autonomous bus

Trials are underway for the UK's first autonomous buses in Scotland. The diesel-engined road buses will have a 'safety driver' and passenger services are expected to open by this summer.

The drive towards a cashless culture has predictably caused ructions with older Swedes who distrust technology or find it inaccessible. However, according to one poll, seven out of 10 Swedes would still like the option of using cash as well as cards or apps, and moves are under way to ensure cash is still an acceptable form of payment – especially as hardware or networks aren't always dependable and a backup form of payment is needed. (As I know all too well: many years ago, the author tried withdrawing cash from an ATM in Gothenburg, Sweden, only to find it couldn't connect to the network and so a visit to a bank was needed, clasping a passport and a bunch of (now long-obsolete) Eurocheques.)

Back home in England, there's more choice at checkouts for cash users, but this may well change as contactless payments are already overtaking cash, especially post-Covid. Although some stores 'tut' when asked for itemised receipts for contactless payments, without one, customers have no way of checking purchases afterwards, especially if there's a problem but no proof of purchase. (For example, a garden centre charged the writer £11.49 for a £1.49 packet of seeds).

The subject of car parking has attracted the author's attention: the writer's local authority ticket machines take either cash or mobile payments using the MiPermit app. As a nod to those 1997 Dial-A-Coke machines, a ticket machine ID is typed into MiPermit to set up a payment, or locations can be stored in the app's favourites. A countdown clock shows the remaining time on the smartphone and SMS reminders are available. So far, in the author's experience, the system has worked really well. UK readers can visit: **www.mipermit.com/** to check availability or set up an account online. (Another common UK app is Ringo – **https://myringgo.co.uk/**) However, if you don't have the correct app already installed, the machines don't accept cash/cards, or there's no phone signal to download the app the first time it's needed, then you can be in trouble. You may well face a hefty penalty ticket levied by unscrupulous operators. This kind of 'gotcha' has discredited the whole idea of cashless parking with some motorists.

Banking on the future

The march towards a cashless society seems relentless but, as discussed, technology is not infallible. What if your phone battery is flat, or you can't get a signal, or you don't have the relevant app installed? What if an ATM is down? Bitter experience of such failures over many years, coupled with a healthy degree of scepticism, means that the author insists on carrying some form of backup, whether it's coins to pay a car park, another payment card or all the necessary logins, PIN numbers and IDs needed to contact a call centre, no matter how time-consuming that may be. A charged-up USB powerbank for the phone is also handy – 'just in case'.

The trend towards mobile and online systems has also heavily impacted the retail banking sector over the past decade. It is reported that nearly 5,000 (or half) of all bank branches have now closed in the UK since 2015. At one time, the writer's local HSBC branch employed more than 30 staff, plus a bank manager who had the discretion to deal individually with customers or traders on the spot. As the use of call centres and online banking grew, staff numbers dwindled and were gradually cut to just three people. Customers who called in were encouraged to use an in-branch terminal to talk with a back-office call centre, and eventually HSBC closed both it and two neighbouring branches altogether. The retail recession has accelerated closures and many small towns in the locality now have no bank branches at all, leaving customers to bank online instead.

You could always give up on the idea of online banking altogether, and let someone else do it for you: one expensive option is to create a Lasting Power of Attorney (LPA) and let a trusted person manage your finances instead (in the UK, see: **www.gov.uk/power-of-attorney** – something best set up by a solicitor), or alternatively ask a bank about a 'third-party mandate', which allows someone to be appointed to handle banking on your behalf.

Younger folks also have their share of pressures growing up in a fast-moving and uncertain digital world. As a sign of the times, today's youngsters are being trained to use prepaid cards and mobile apps to control personal finances and deal with payment technologies, ready to face the future more confidently. The GoHenry service offers specially designed apps both for kids and their parents, and helps with setting targets, sharing their progress and managing spending. The GoHenry subscription service is available in both the US and UK, and claims to have two million users – sign up at: **www.gohenry.com**

An electric bus battery exploded and destroyed the vehicle in suburban Paris last April. (Image: Vixx/YouTube).

Other news

The UK's first autonomous buses are taking to Scotland's roads in live trials prior to launching a passenger service this summer. The pilot involves five single-decker diesel buses, equipped with Fusion Processing's sensor and control technology, CAVstar, running on pre-selected roads without the 'safety driver' having to intervene or take control, or so it is hoped. The buses are destined to pass over Scotland's Forth Road Bridge to the Edinburgh Park Train and Tram interchange. The scheme is funded jointly by the UK Government and industry, and the project is keen to reassure bus users about the merits of these autonomous vehicles. More details at: **www.cavforth.com**

Still on the subject of buses, alarming footage is circulating showing what happens when an electric bus has a meltdown and catches fire. In China in 2021, a row of five open-sided electric buses was destroyed when a fault developed in one of them, causing an intense fire that quickly spread to neighbouring vehicles. See: **https://youtu.be/T71cVhxG_v4**

Electric vehicle battery hazards were highlighted in March when the car-carrier vessel the *Felicity Ace*, transporting 4,000 luxury VW Group cars, went up in flames off the coast of Portugal, causing over $400m of losses. Intense fires in electric vehicle batteries accelerated the fire, it was reported, and the vessel eventually sank in the Atlantic Ocean. More recently, in Paris an electric coach erupted like a volcano when its battery pack failed and destroyed the vehicle. The footage, taken in April, is on YouTube at: **https://youtu.be/5r-yN8SugWM**

Israeli EV battery maker StoreDot, mentioned in previous columns, recently livestreamed a demo of its extreme fast charging (EFC) '100in5' battery technology during Israel's EcoMotion Week 2022. The system aims to deliver [up to] 100 miles of motion from 5 minutes of charge, and the workshop bench demo shows 0-80% charging in ten minutes. (Readers can see the lab demo at **https://youtu.be/2gQIGUSsCyA**) StoreDot also announced it has won strategic investment from the Volvo Cars Tech Fund.

British consumers wanting to enter the electric vehicle market are increasingly being sold the idea of 'subscribing' to their cars, something that sounds nicer than renting. The new website **On.to** promises 'all-inclusive electric car subscriptions' with a simple monthly deal that bundles insurance, charging, servicing and breakdown cover, together with free charging and a 750-miles-a month travel allowance. Prices range from £379 a month for a tiny VW Up! all the way to £1,299 a month for a Jaguar I-Pace.

In earlier columns I highlighted Virgin Orbit's space-launching system which will propel small satellites into space using a carrier rocket launched from a specially adapted jumbo jet, a 747 called *Cosmic Girl*. Thanks to modern component miniaturisation, heavy-lifting space rockets are no longer needed when launching small and powerful space satellites or cubesats into orbit. Readers might recall that Spaceport Cornwall (**https://spaceportcornwall.com**) in south-west England has been chosen as one such take-off site. The UK Government has now confirmed that two cubesats will be launched from Cornwall this summer to test GPS, imaging and data processing in space for the Ministry of Defence. The Government project paves the way for the UK's forthcoming Minerva space programme.

That's all for this month's roundup – see you next month for another helping of electronics news in *Net Work*.

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Single-Chip Silicon Labs FM/AM/SW Digital Radio Receiver

Si4732 Receiver
105.900 MHz
St 100k SNR 33dB
TUNING
VOLUME
BANDWIDTH
SW
AM
FM
ON
Si4730 Receiver
621 kHz BW 2.5
St 9kHz
BANDWIDTH
TUNING
VOLUME
AM
FM

By Charles Kosina

The ultimate in FM/AM radio reception technology is the single-chip solution. All you have to do is connect some antennas to pins on an IC, send it some serial commands, and stereo audio comes out the other end. As a result, these Silicon Labs chips make building a capable radio receiver a doddle. It's straightforward to set up and use, fits in a compact case and runs from a simple AC plugpack.

I was happy with my AM/FM/SW Receiver design from the December 2021 issue, at least in terms of how easy it is to build, ease of use and coverage of multiple radio bands. But I still felt that its overall performance left a little to be desired. I was also not happy that I didn't have enough information for full digital control of the BK1198 radio chip.

While that radio design was relatively straightforward as radios go, it would have been a lot simpler if I could have gotten the digital control working.

In the last few years, several new chips have appeared that greatly ease radio receiver design. Many of these are from Silicon Labs – the offer about 34 varieties of chips in the Si473x family, and you can download the main data sheet from their website: **https://bit.ly/pe-jul22-skyw**

They have a similar architecture to the BK1198 chip I used for the December 2021 design. One major advantage of the Silicon Labs chips is the documentation; whereas information on the BK1198 is sparse, to say the least, the application note for the SiLabs chips runs to 321 pages! (Check it out at: **https://bit.ly/pe-jul22-sky2**).

The board that I have laid out here is suitable for a prebuilt module with the Si4730 chip, or a standalone Si4732 chip. Both are available on AliExpress at quite low prices. The Si4730 only handles the standard AM and FM bands, whereas the Si4732 can be programmed to cover longwave and shortwave. Both can decode FM stereo. The specifications give the bands shown below.

Worldwide FM band support	64–108MHz
Worldwide AM band support	520–1710kHz
SW band support (Si4734/32/35)	2.3–26.1MHz
LW band support (Si4734/32/35)	153–279kHz

But what about the gaps between the bands? I decided to experiment and set frequencies in these gaps. And what a surprise; with the Si4732 chip, I could select any frequency from 153kHz up to 30MHz by sending the appropriate code to the chip. No gaps! Whether there is anything of interest in the gaps is another matter.

Thus, I have the AM band programmed from 153kHz to 1730kHz, and the SW band from 2MHz to 30MHz.

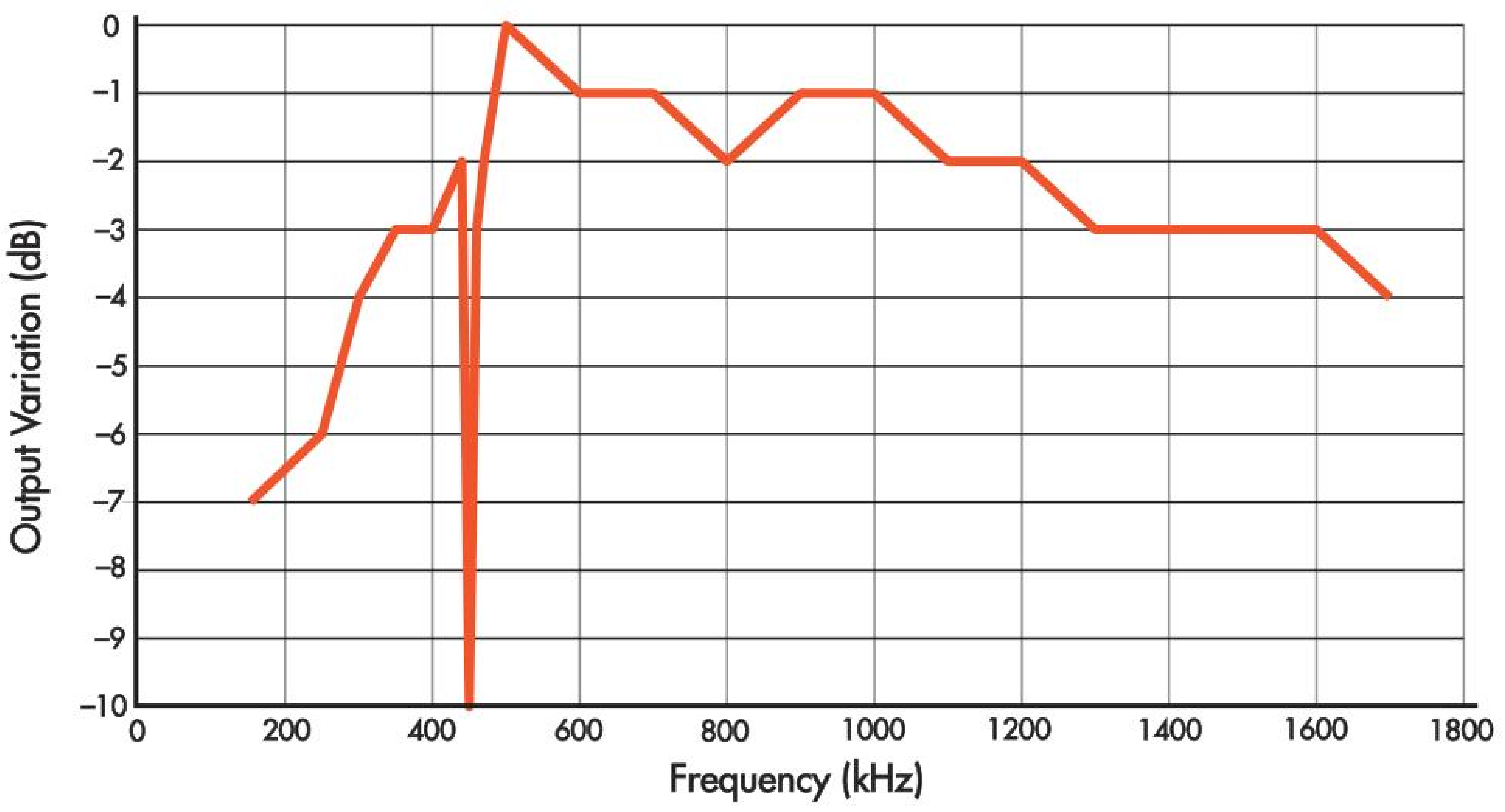
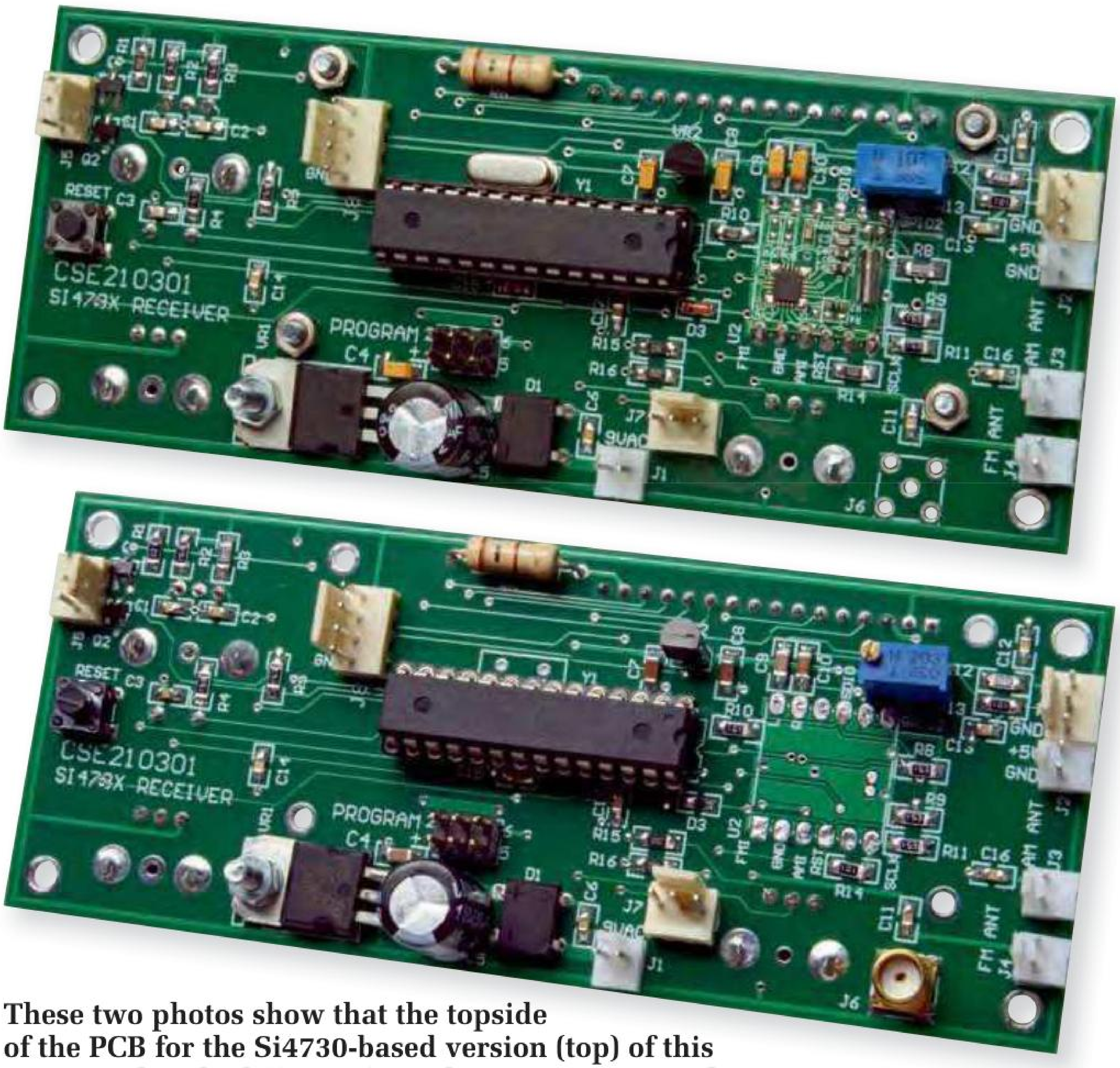


Fig.1: the radio's sensitivity across a widened AM band, from 153kHz to 1.7MHz. Except for a dip around 445-455kHz (typical intermediate frequencies), the result is pretty flat. Across the standard AM broadcast band of 550-1720kHz, there is only about 4dB variation.



These two photos show that the topside of the PCB for the Si4730-based version (top) of this project is barely different from the Si4732 version (bottom). Ignore the additional screws/nuts as those are just for mounting the screen.

Performance

On the FM band, a short piece of wire inside the box will bring in most of my local (Melbourne, Australia) stations with a good SNR.

With an outdoor long-wire antenna connected directly to the AM antenna input, I could get many stations with an SNR of 25dB or better without any ferrite rod. This way, there is not a single inductor required in the circuit. Using a ferrite rod, the weaker stations came through, but there was a lot of hash caused by all the electronics in my lab.

I made a plot of sensitivity on the AM band from 153kHz to 1700kHz, shown in Fig.1. Note the sharp dip at 450kHz. I have no idea why this is, but it is near the intermediate frequency of most superhet receivers, so it is of no consequence.

On shortwave, the sensitivity is comparable to the AM band (see Fig.2). This is not brilliant, but adequate. There were a few 'birdies' on some frequencies – eg, 8MHz, 14MHz and 16MHz – which made SNR measurement difficult. Above 22MHz, the SNR display did not seem to give sensible readings, although performance up to 30MHz seemed the same as at 20MHz.

The audio drive capability of the SiLabs chips is not stated in the data sheets. I determined experimentally that the minimum load resistance on the headphone output is 1.6kΩ. Any less, and clipping will occur.

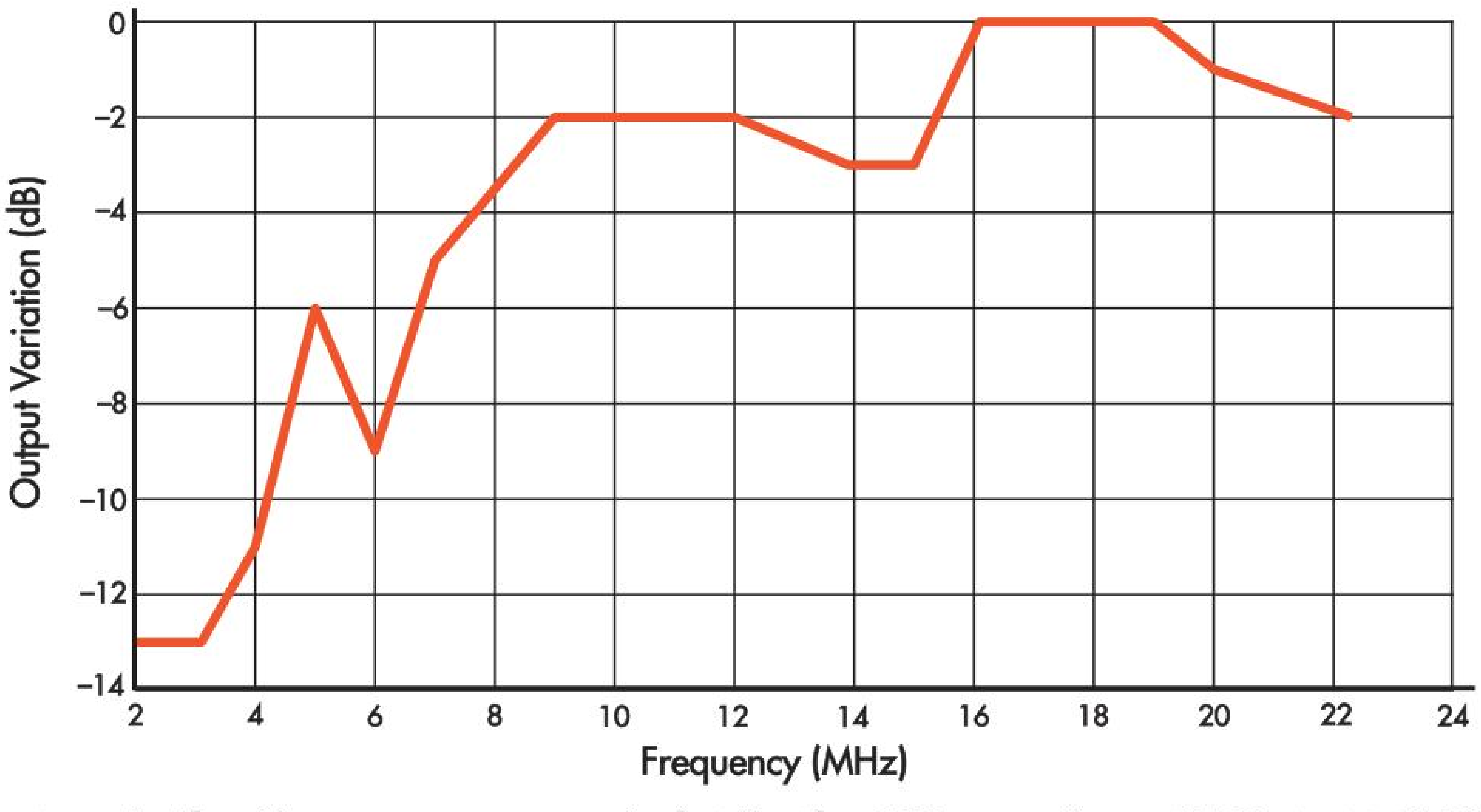


Fig.2: a similar 'frequency response' plot for the SW range from 2MHz to 22.3MHz.

The maximum output with this load is 250mV peak-to-peak, or about 88mV RMS for a sinewave, giving less than 1mW. It still works with low-impedance headphones, although at maximum volume there will be some distortion. Sennheiser 60Ω headphones gave an acceptable listening level in a quiet environment.

Panasonic noise-reducing headphones with a 330Ω input resistance (with the noise reduction turned on) gave a considerably higher sound level. Feeding the signal into external amplified speakers gave good-quality sound.

Because of this weak output, I have added an op amp buffer that provides drive capability for low-impedance headphones, while also providing enough voltage swing for insensitive high-impedance 'phones. This is also useful if you are feeding the audio to a preamp or amplifier, as the signal is closer to 'line level'.

When the tuning knob is rotated, each pulse from the shaft encoder sends out six bytes via I^2C and then receives seven bytes of status. This takes a significant time, so if you spin the tuning knob too rapidly, the encoder pulses are missed, and you only get a small frequency change. Just slow down the rotation.

Circuit description

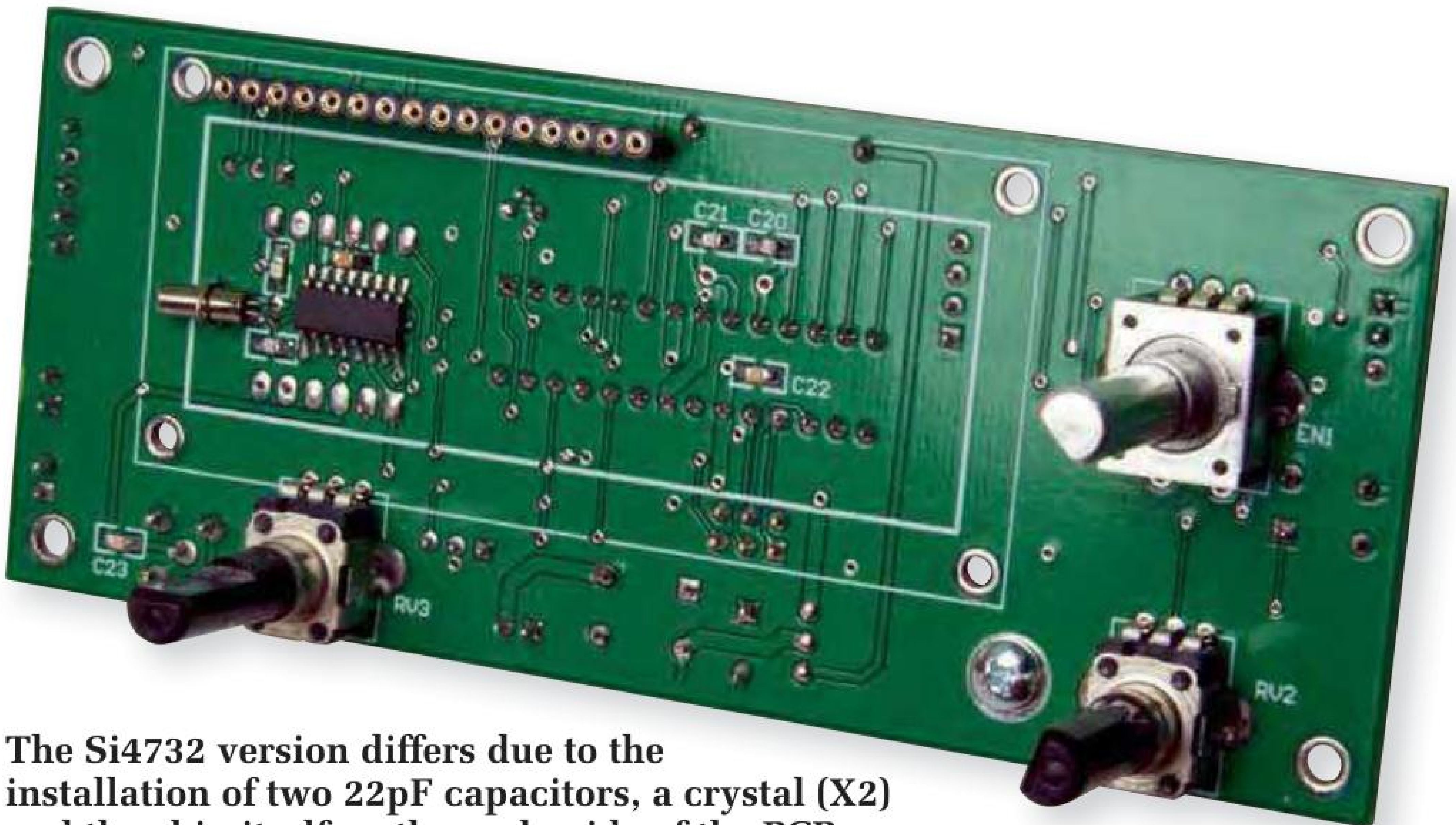
The full schematic is shown in Fig.3. The Si4730 module includes the 32.768kHz crystal and associated capacitors. The FM antenna is connected to the module's FM input via a 1nF capacitor, while the AM band requires a ferrite rod, typically 400µH.

An optional 10nF capacitor joins the two antenna inputs, allowing a single length of wire to provide both FM and AM reception in metropolitan areas. The SEN line is tied high internally on the Si4730 module.

The audio output is coupled to header CON4. The drive strength from the radio chip itself is just adequate to drive 60Ω headphones; as hinted above, depending on the 'phones, the volume level can be a bit low, and distortion can be higher than we'd like.

The dual op amp (IC3) in the final version is not present in the prototypes shown. This gives a voltage gain of 4 and low-impedance output, enough to drive just about any headphones or earphones to a decent volume level (even insensitive types), and possibly even very efficient unpowered speakers.

Alternatively, an external audio amplifier, such as PC-style speakers can be used, with or without the op amp. If you don't need the op amp, you can simply bridge pin pairs 1/3 and 5/7, to feed the radio chip's output to CON4.



The Si4732 version differs due to the installation of two 22pF capacitors, a crystal (X2) and the chip itself on the underside of the PCB.

CON4 also has +5V and GND pins. This supply might be used for a small amplifier module mounted in the same case, to drive 8Ω speakers. I don't recommend Class-D amplifiers because they could generate hash which will interfere with radio reception, much the same as a switching regulator.

Control is via a standard I^{2}C serial bus and a reset line. I have specified a 32KB ATmega328P chip in a DIL package, although I used the 16KB ATMega168 in my prototype; the program only occupies 68% of its 16KB of Flash, and I have heaps of these chips left over from a previous project. Besides the Flash size, they are essentially identical.

The display is a standard 16x2 alphanumeric LCD module. There is provision for an external crystal for the ATmega chip, but I found the internal 8MHz RC oscillator quite adequate.

The processor runs from 5V, whereas the SiLabs chip requires 3.3V. This is not a problem for the I^{2}C interface, as the output is open-drain, and the 15kΩ pull-up resistors go to 3.3V. There are also two 1kΩ series current-limiting resistors between the I^{2}C outputs of the micro and the radio module's inputs as a precaution against incorrect programming of the I^{2}C pins.

The typical value of an I^{2}C pull-up resistor is 4.7kΩ, but the SCL and SDA pins on the SiLabs chip have limited drive capabilities. Operation with 4.7kΩ pull-ups could be marginal, especially given the 1kΩ series protection resistors. Hence the use of 15kΩ pull-ups; lower values would give a marginal low voltage with either pin when pulled externally low, via those 1kΩ resistors. I have not found any problems with these higher-value pull-up resistors (eg, sensitivity to EMI).

Tuning is by a standard shaft encoder with a pushbutton switch (RE1). The switch cycles through different step sizes on the bands. The external band switch, S3, toggles between AM and FM modes.

I used an ON-OFF-ON type switch to provide for three bands. This gives three different voltages which can be read by the analogue-to-digital converter (ADC) input on the ATmega, PC3 (pin 26). If the Si4730 module is used, there is no SW band, so you should use a two-position switch instead.

Another ADC input, PC0 (pin 23), monitors the voltage at the wiper of potentiometer VR2 which sets the volume. The reading is scaled and sent via the I^{2}C lines to control the volume of the SiLabs chip.

A third ADC input at PC1 (pin 24) reads the position of potentiometer VR3; the reading is scaled and sent to the SiLabs chip to adjust the bandwidth on the AM band. I could have used a multiple position switch, but this is a simpler and cheaper option.

The bandwidths that can be selected are 1.0, 1.8, 2.0, 2.5, 3.0, 4.0 and 6.0kHz. The potentiometer that I have used has a centre detent which gives a 2.5kHz bandwidth, but this is optional. There is no bandwidth option for FM.

Using the Si4732 chip

For those who wish to include SW or LW bands, you can use the Si4732 chip instead of the Si4730 module. This comes in an SOIC SMD package, which is not difficult to solder. There are only slight changes to the circuit, as shown in Fig.4.

The SENB pin goes to ground on the Si4732, which gives it a different I^{2}C address to the Si4730. It requires an additional crystal and three capacitors. The Si4730 module I^{2}C addresses are C6 hex for writing, and C7 for reading. With the Si4732 chip, the corresponding addresses are 22 and 23 hex.

Don't load both the Si4730 module and Si4732 chip. Although they have different I^{2}C addresses, the loading on the RF inputs is such that it severely degrades sensitivity.

You will note that the I^{2}C bus is made externally accessible via CON8, together with the +5V supply. This could be useful in future for expansion, or as a debugging aid.

The power supply may be 9V AC or 9-12V DC via CON1. If a DC supply is used, it must not be a switching type – its hash can wipe out the AM band.

A 7805 regulator supplies the ATmega chip and the LCD module, while a small TO-92 linear regulator provides 3.3V for the SiLabs chip.

Debugging interface

MOSFETs Q1 and Q2 provide a serial debugging interface. This was invaluable for debugging purposes, but not required if you just want to use the radio. It is set up for 38,400bps, eight data bits, one stop bit and no parity.

Microcontroller IC2 is programmed via the standard 6-pin header, CON9. A pushbutton switch is provided to reset IC2.

Component Selection

While I try to make sure that components can be sourced locally, it is not always possible. In this case, several major components have to be sourced from international suppliers.

There are a few suppliers of the Si4730-V2.0 module on AliExpress that sell it from £5 to £12. Make sure it's the version with six connections on each side of the board. There are some with only five connections that will not fit. As with most orders from China, be prepared for a fairly long delivery time.

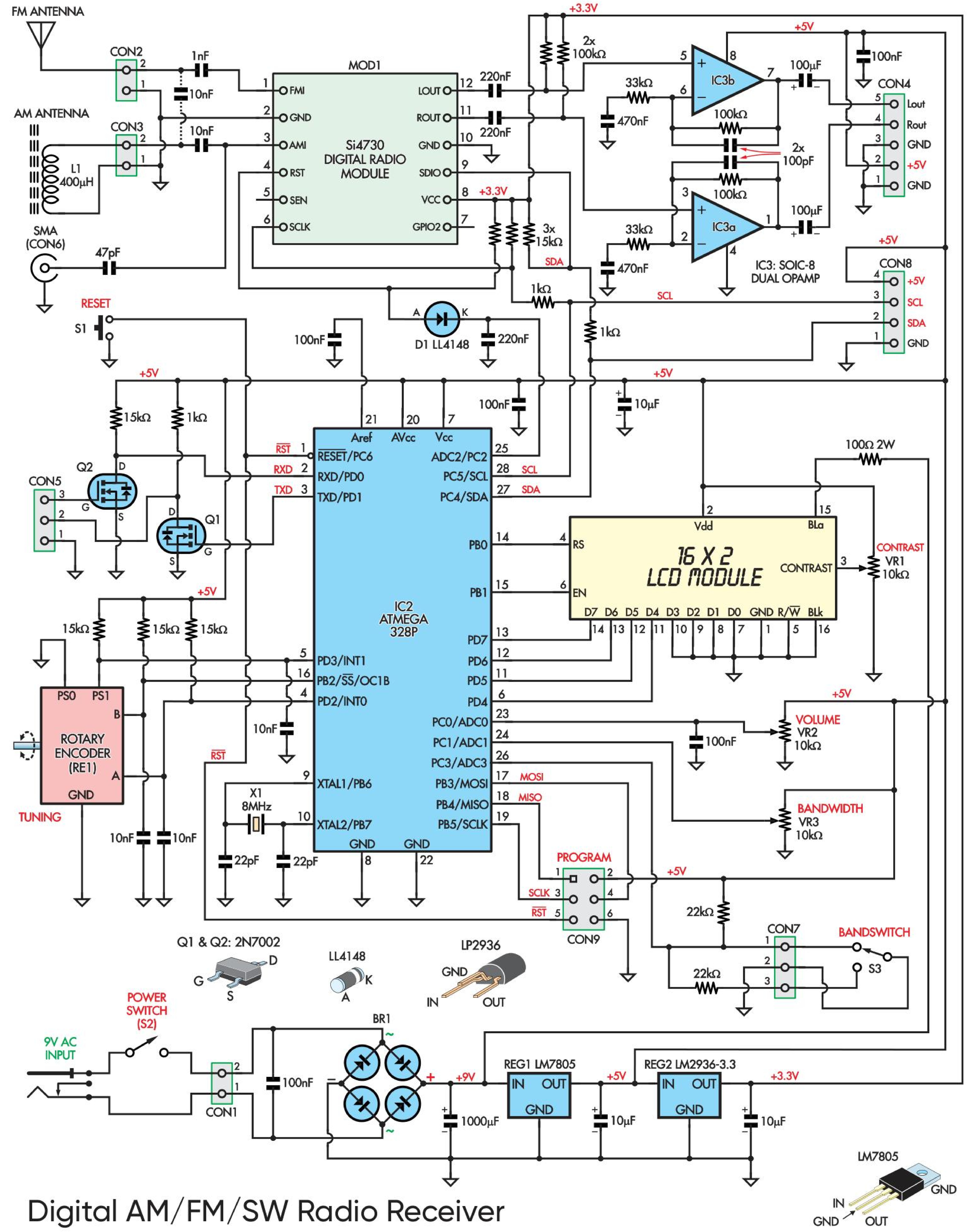
The Si4732 chip is manufactured in the SOIC-16 package. It is available on AliExpress, and also Digi-Key and Mouser, where you can order it along with other parts.

Apart from the 1000µF electrolytic and the 2W resistor, all other resistors and capacitors are either 1206 or 0805 (imperial) size SMDs, and there are no fine-lead-pitch devices to worry about.

There are various colours of backlighting for the LCD module. We much prefer the white-on-blue version to the old-fashioned yellow/green variety. This type is available from several suppliers on eBay. But if you don't mind waiting, the LCD module can cost as little as about £1.50 from China.

Since we're using the parallel interface, you won't need the I^{2}C serial interface board supplied with some of them.

The LCD is mounted off the main PCB with standoffs, and connected using the supplied standard header plugging into a low-profile PCB-mounting socket strip. The LCD height above the board means that the two pots and rotary encoder need 25-30mm-long shafts. The parts list shows suggested components.


FM ANTENNA
CON2
1nF
10nF
AM ANTENNA
CON3
L1
400µH
SMA
(CON6)
47pF
MOD1
FMI
GND
AMI
RST
SEN
SCLK
Si4730
DIGITAL RADIO
MODULE
LOUT
ROUT
GND
SDIO
VCC
GPIO2
220nF
+3.3V
2x
100kΩ
3x
15kΩ
SDA
SCL
1kΩ
+5V
IC3b
IC3a
33kΩ
470nF
100kΩ
2x
100pF
100µF
IC3: SOIC-8
DUAL OPAMP
100nF
CON4
Lout
Rout
GND
+5V
GND
CON8
+5V
SCL
SDA
GND
RESET
S1
D1 LL4148
A
K
220nF
100nF
10µF
15kΩ
1kΩ
Q2
Q1
CON5
D
G
S
RST
RXD
TXD
Aref
AVcc
Vcc
RESET/PC6
RXD/PD0
TXD/PD1
ADC2/PC2
PC5/SCL
PC4/SDA
PB0
PB1
PD7
PD6
PD5
PD4
PC0/ADC0
PC1/ADC1
PC3/ADC3
PB3/MOSI
PB4/MISO
PB5/SCLK
IC2
ATMEGA
328P
PD3/INT1
PB2/SS/OC1B
PD2/INT0
XTAL1/PB6
XTAL2/PB7
GND
X1
8MHz
22pF
10nF
MOSI
MISO
100Ω 2W
Vdd
BLa
RS
EN
16 X 2
LCD MODULE
CONTRAST
D7 D6 D5 D4 D3 D2 D1 D0 GND R/W BLk
CONTRAST
VR1
10kΩ
VOLUME
VR2
10kΩ
BANDWIDTH
VR3
10kΩ
PS0
PS1
B
A
ROTARY
ENCODER
(RE1)
GND
TUNING
PROGRAM
SCLK
CON9
22kΩ
CON7
BANDSWITCH
S3
Q1 & Q2: 2N7002
LL4148
LP2936
IN
OUT
POWER
SWITCH
(S2)
9V AC
INPUT
CON1
BR1
+9V
1000µF
REG1 LM7805
REG2 LM2936-3.3
IN
OUT
GND
10µF
+3.3V
LM7805
GND
IN
GND
OUT

Digital AM/FM/SW Radio Receiver

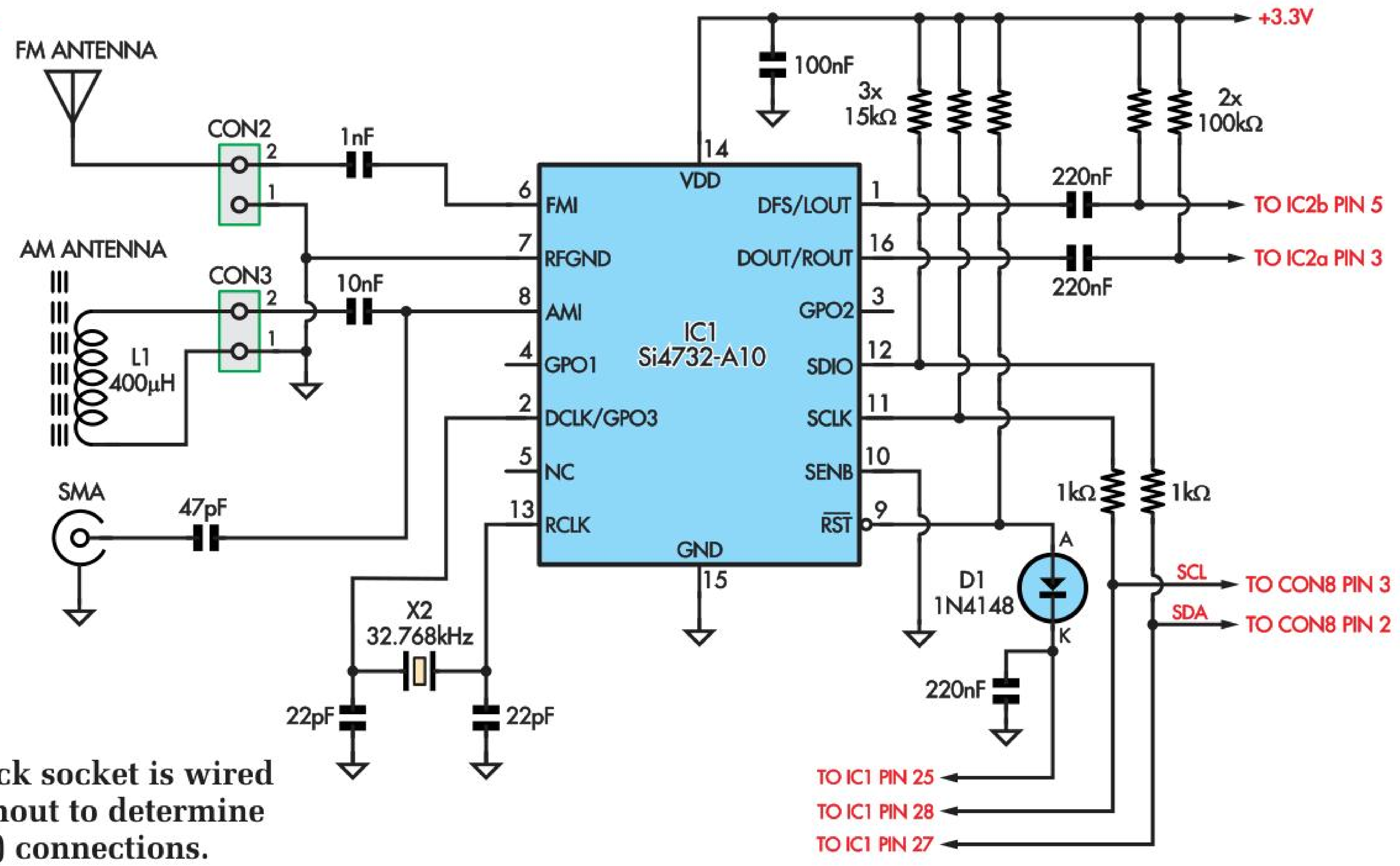
Fig.3: there isn't a lot to the radio circuit thanks to the Si4730 radio module. The antennas at left are simply coupled to the module using capacitors, while the audio outputs on the right-hand side feed into a pair of op amp buffer/gain stages, which are better at driving headphones than the module by itself. IC2 controls the radio over an I^{2}C serial bus while monitoring user input via rotary encoder RE1, and displaying tuning and signal strength information on a two-line LCD.

Construction

A word of caution. The crystal on the tiny SI4730 module is not firmly attached and can be easily bent to one side and damage the board. I can vouch for that from experience! I recommend a spot of superglue to attach it firmly to the board. You might want to consider ordering two of these modules to be on the safe side.

The main circuit board (coded CSE210301C) is double-sided with

Fig.4(a): if you want SW reception, all you have to do is leave off the Si4730 module (MOD1) and instead fit IC1, its 100nF supply bypass capacitor, crystal X2 and its two 22pF load capacitors. All the other components shown here were in the original circuit (Fig.3) and are only duplicated to clarify how IC1 is connected to the rest of the circuit.


FM ANTENNA
AM ANTENNA
CON2
CON3
1nF
10nF
L1
400µH
SMA
47pF
X2
32.768kHz
22pF
22pF
100nF
3x
15kΩ
2x
100kΩ
+3.3V
220nF
220nF
TO IC2b PIN 5
TO IC2a PIN 3
IC1
Si4732-A10
VDD
FMI
RFGND
AMI
GPO1
DCLK/GPO3
NC
RCLK
GND
DFS/LOUT
DOUT/ROUT
GPO2
SDIO
SCLK
SENB
RST
1kΩ
1kΩ
D1
1N4148
A
K
220nF
SCL
SDA
TO CON8 PIN 3
TO CON8 PIN 2
TO IC1 PIN 25
TO IC1 PIN 28
TO IC1 PIN 27

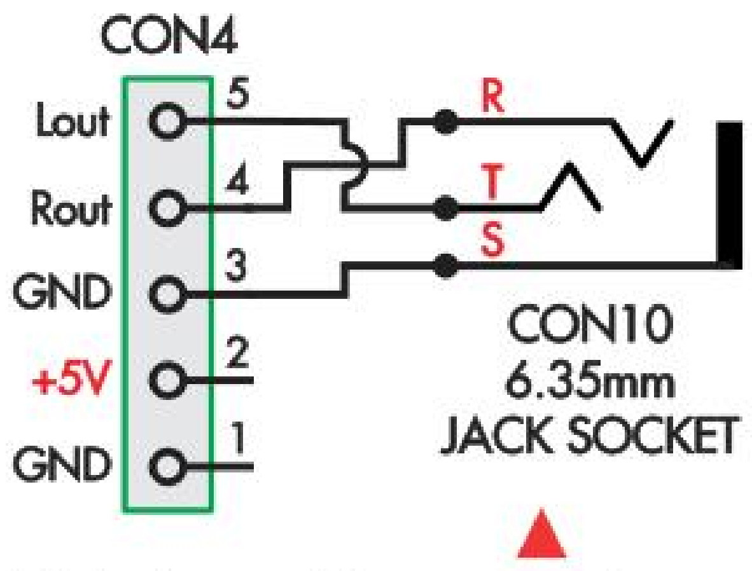

CON4
Lout
Rout
GND
+5V
GND
R
T
S
CON10
6.35mm
JACK SOCKET

Fig.4(b): how the panel-mount jack socket is wired to CON4. Check your socket's pinout to determine the tip (T), ring (R) and sleeve (S) connections.

components on both sides. It measures 123 x 49.5mm and is available from the *PE PCB Service*. Both *Receiver* versions use the same PCB; either you mount the Si4730 module on one side, or the Si4732 chip on the other. Refer to overlay diagrams Figs.5 and 6, and ensure that you either fit the module as shown in Fig.5, or the components in the red oval in Fig.6 – *not both*.

Start by mounting the 16-pin chip. This is the SOIC-16 type with pins spaced widely enough that they can be soldered individually using a fine-tipped iron.

First, apply some flux paste to the pads to reduce the risk of bridging between pins. If bridges do form during soldering, use more flux paste and some solder wick to remove it.

Next, fit the SMD capacitors on the underside of the board. Note that the two 22pF capacitors (values in parentheses) are only needed if you wish to use a crystal oscillator for the ATmega168/ATmega328 chip. If not, we suggest you leave them off.

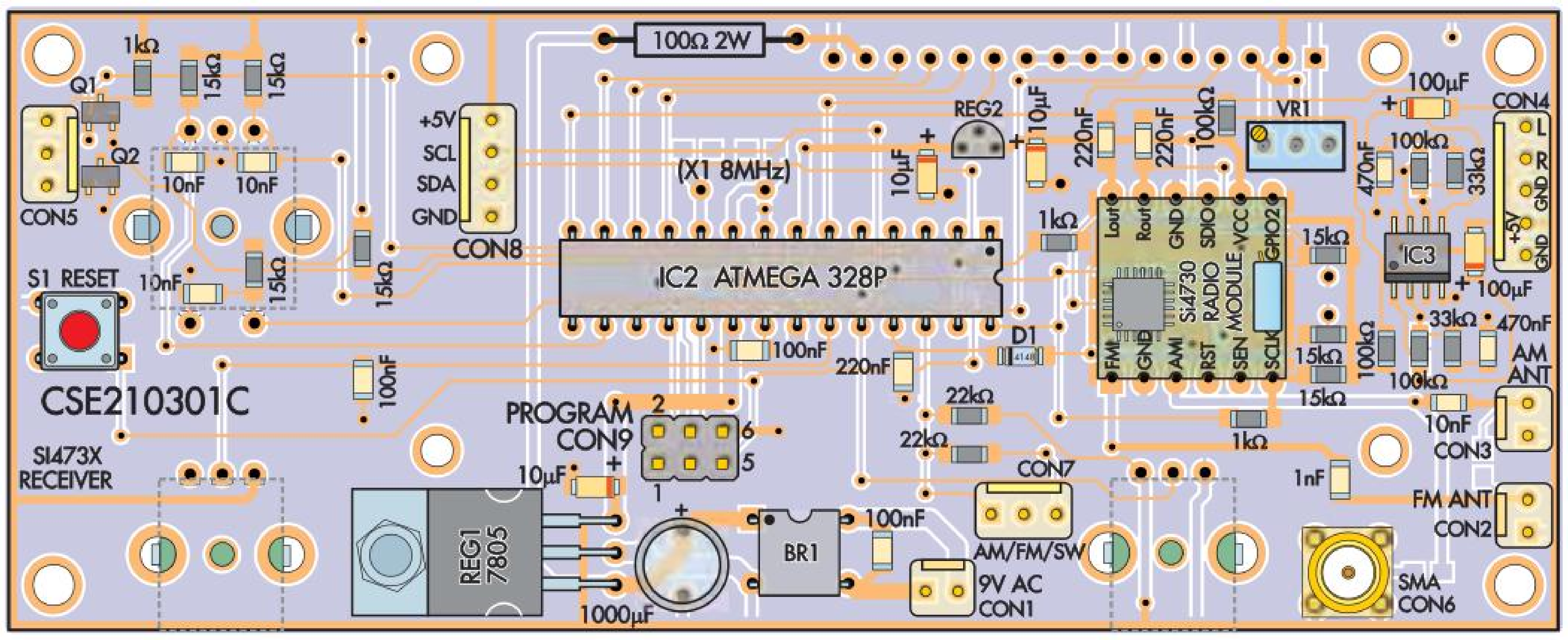
The other side of the board has most of the components. Install the remaining surface-mount parts next. If you are using the Si4730 module, make sure it's placed accurately. It needs plenty of solder flowing into the 'half holes' either side of the module PCB.

Ensure that the 10µF and 100µF tantalum capacitors are placed with the correct polarity. The striped end is positive, so face the striped ends towards the '+' symbols on the PCB. Then add the through-hole components, possibly including the optional 8MHz crystal.

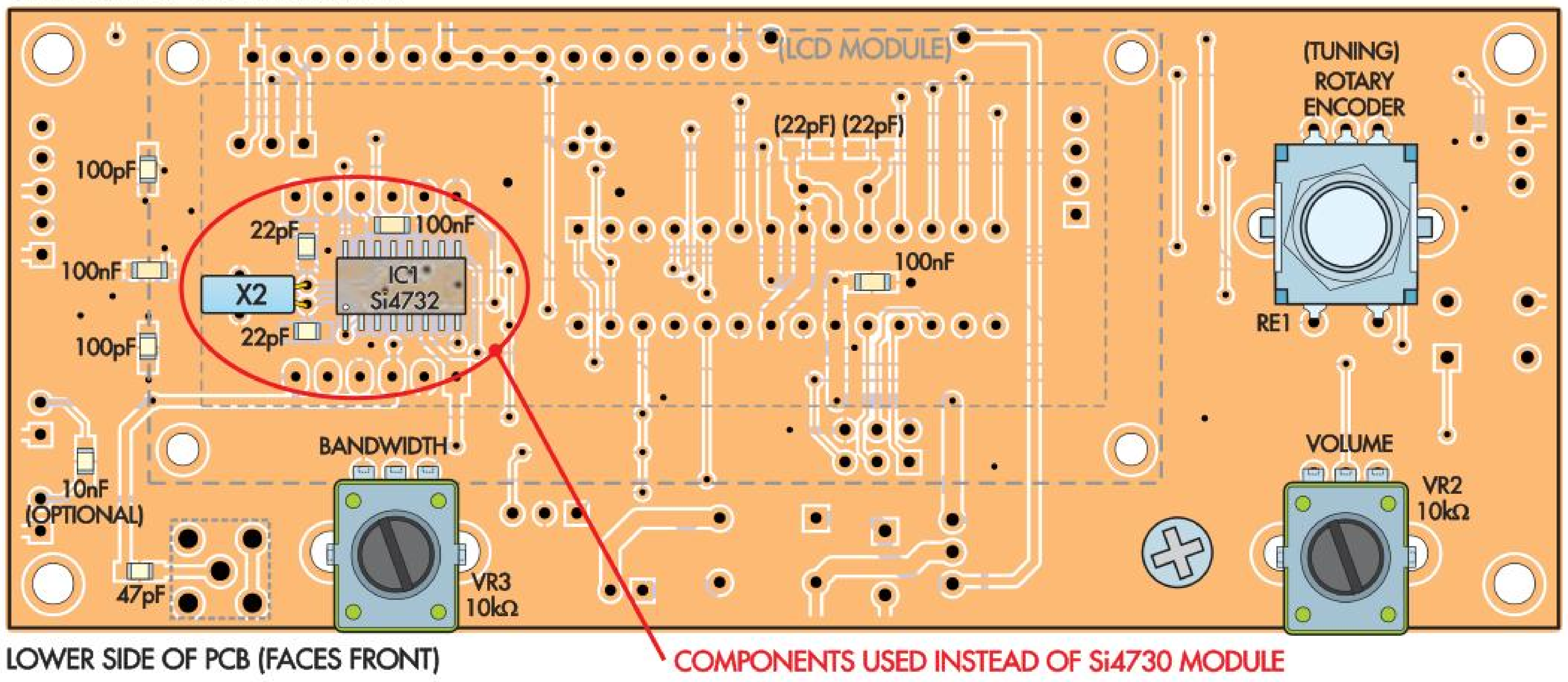
There is also provision for an SMA socket, CON6, although I didn't use it. This is an alternative input for the AM, LW and SW bands.

Ideally, I prefer the LCD module to be removable; hence, I plugged it into a socket strip. The matching headers are not that easy to find, but the parts list mentions suppliers. The LCD is then attached using 9mm untapped spacers (Jaycar HP0862 or Altronics H21362) and M2.5 x 15mm screws and nuts.

The last components to attach are the two potentiometers (VR2 and VR3) and rotary encoder RE1 on the LCD side. Finally, give the board a good wash on both sides with circuit board cleaner.


100Ω 2W
1kΩ
15kΩ
15kΩ
Q1
Q2
10nF
10nF
CON5
S1 RESET
10nF
15kΩ
15kΩ
CSE210301C
SI473X
RECEIVER
+5V
SCL
SDA
GND
CON8
(X1 8MHz)
IC2 ATMEGA 328P
REG2
10µF
10µF
220nF
220nF
100kΩ
VR1
100µF
100kΩ
470nF
33kΩ
CON4
Si4730 RADIO MODULE
IC3
15kΩ
100µF
33kΩ
470nF
100kΩ
100nF
220nF
D1
1kΩ
15kΩ
15kΩ
100kΩ
AM ANT
10nF
CON3
FM ANT
CON2
1nF
1kΩ
22kΩ
22kΩ
CON7
PROGRAM
CON9
10µF
100nF
REG1
7805
BR1
100nF
AM/FM/SW
9V AC
CON1
1000µF
SMA
CON6

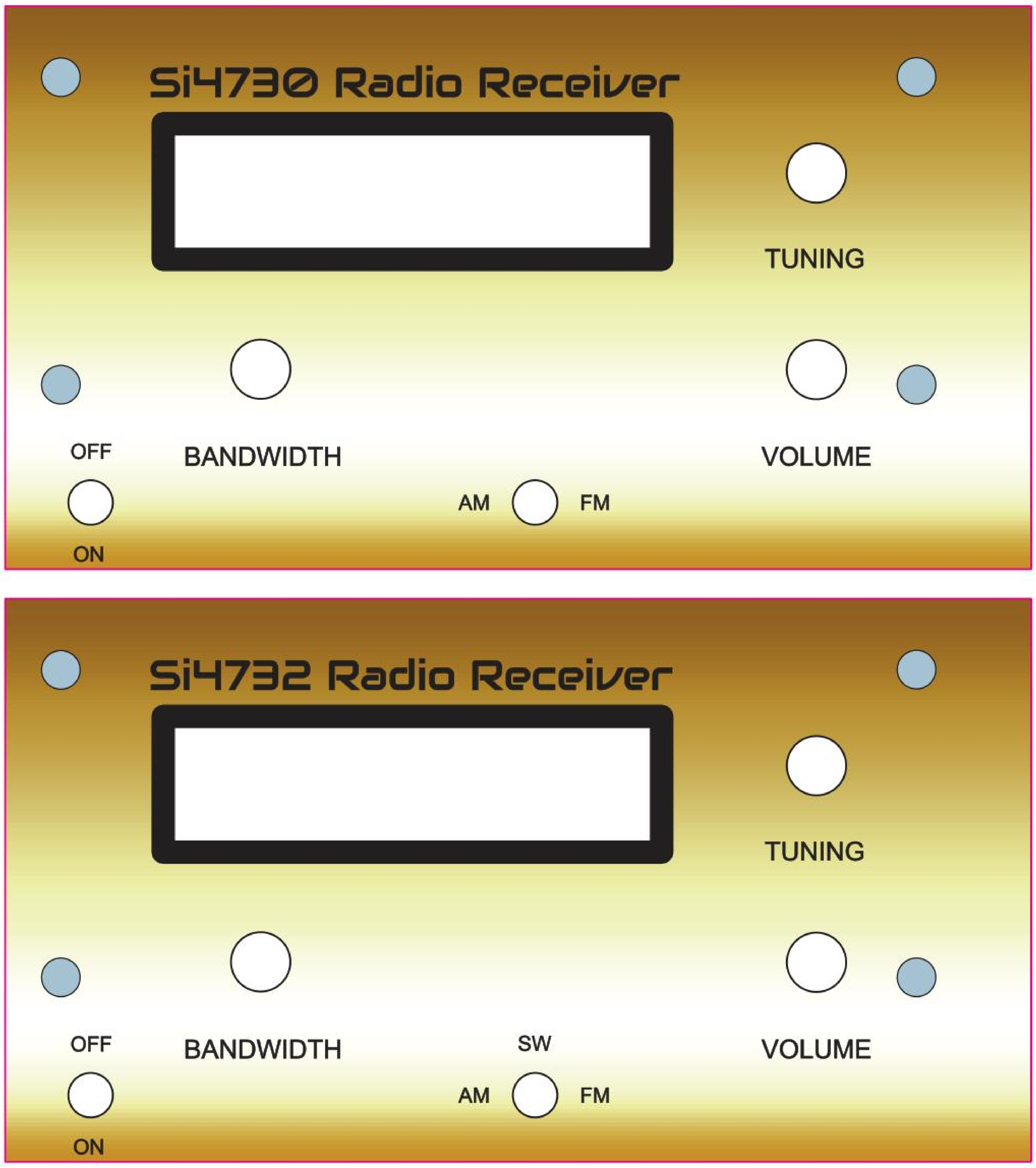
UPPER SIDE OF PCB (FACES REAR)


(LCD MODULE)
(22pF) (22pF)
100pF
100nF
100pF
22pF
100nF
X2
IC1
Si4732
22pF
100nF
(TUNING)
ROTARY
ENCODER
RE1
BANDWIDTH
VR3
10kΩ
VOLUME
VR2
10kΩ
10nF
(OPTIONAL)
47pF
COMPONENTS USED INSTEAD OF Si4730 MODULE

LOWER SIDE OF PCB (FACES FRONT)

Figs.5 and 6: most of the components mount on the top side of the PCB; apart from a few SMDs, the only parts on the bottom are the two pots, the rotary encoder and crystal X2 (if IC1 is fitted). It's best to fit all the SMDs on the underside, then the SMDs on the top, then the through-hole parts on the top, then the underside. Ensure the polarised parts like the radio module, all the ICs, the aluminium and tantalum electrolytic capacitors, bridge rectifier BR1, diode D1 and trimpot VR1 are orientated as shown.

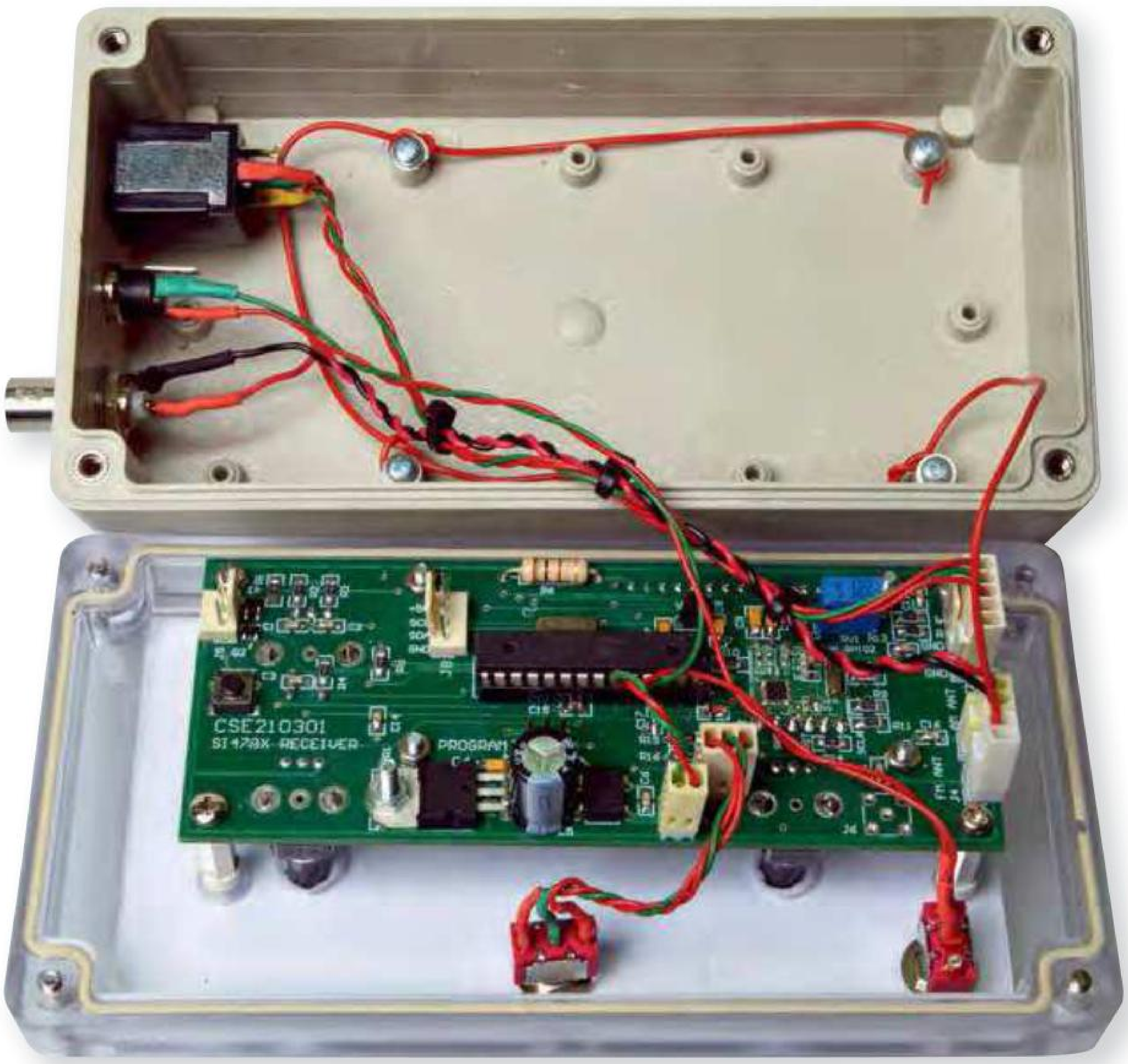
Errata: if using the specified part, REG2 should be mounted upside down relative to the overlay. Otherwise you can mount it on the underside of the PCB, ensuring it doesn't foul the front panel. This is due to the input and output pins being swapped on the PCB footprint.



Figs.8 and 9: (shown 85% full size) these panel labels are available to download from the July 2022 page of the PE website, so you can print them, cut them out and attach them to the inside (or outside) of the box lid.

Preparing the enclosure

I encased the radio prototypes in a Hammond RP1175C box, which has a clear lid. This avoids having to make a rectangular cutout for the LCD, so you can drill all the holes. It is available from Mouser, Digi-Key, Rapid and others. You could use a larger case that's locally available, but that would make the radio a bit less convenient to use.



This is how I wired up the prototype Si4730-based radio.

You can place the power input connector, headphone jack and BNC antenna connector on any convenient surface. I chose the righthand side of the box.

The headphone jack presents something of a problem. The case thickness is too much for easily obtainable 3.5mm stereo jacks. The simplest solution is to use a 6.35mm jack, and if necessary, a 3.5mm adaptor (eg, Jaycar PA3590).

The drilling details are shown in Fig.7; use this as an initial template to locate the circuit board mounting holes (D) and the toggle switch holes (B). As accuracy is required, the blank circuit board can then be used as a template for drilling the mounting holes.

Use a countersinking tool so that the screw heads will be flush with the front panel. You will note that there is a small hole in the centre of the encoder and two potentiometers.

Once the four mounting holes (D) are drilled, attach the board to the panel with 3mm screws and drill 1mm holes through the centre of the two potentiometers and encoder positions, to accurately mark the centres of the 8mm holes (A).

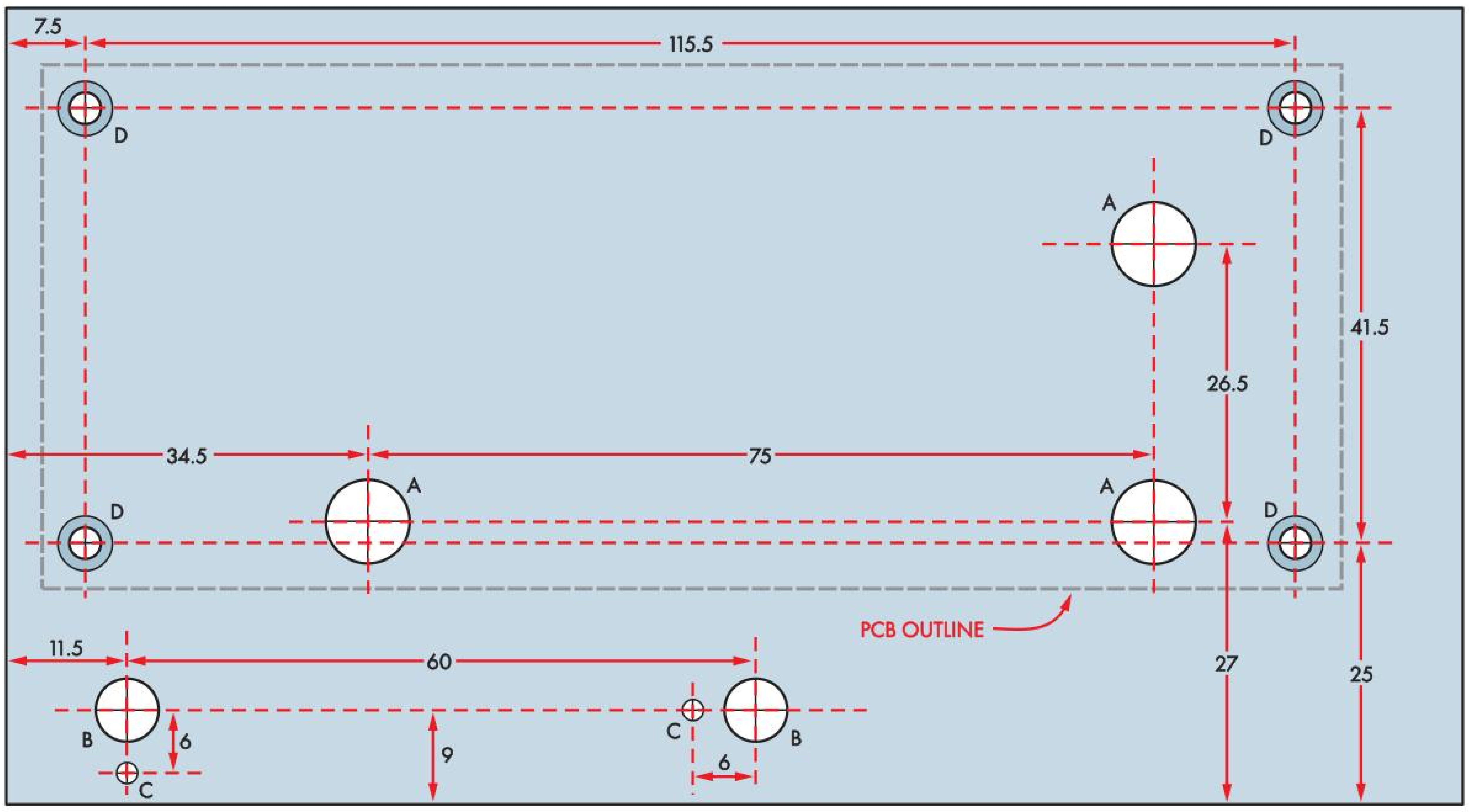
I printed the 139 x 76mm front panel label on heavy photographic paper, and it fits neatly in the slot on the transparent panel.

Fig.8 is the panel label for the Si4730 module-based version, while Fig.9 shows the label for the Si4732-based version. The only difference is in the labelling for the band change switch, adding the SW option for the Si4732 chip. You can download these labels from the July 2022 page of the *PE* website and print them out.

Use a sharp blade to cut out the slot for the LCD and the five holes for potentiometers, encoder and switches, then cut out the panel and slot it into the inside of the clear lid. It should be a neat fit.

Attach the circuit board to the back of the front panel using 12mm-long M3 countersunk head screws at the front and M3 x 6mm screws at the back. 18mm-long spacers are needed, which can be made from a 12mm threaded spacer plus an untapped 6mm spacer stacked. You can use other spacer combinations to give the required 18mm.

The potentiometer and encoder shafts are 6mm in diameter. Be careful if you are using metric knobs, as some might not be suitable for the shafts. Choose the types with a grub screw



7.5
115.5
D
D
A
41.5
26.5
34.5
75
A
D
A
D
PCB OUTLINE
11.5
60
27
25
B
6
C
9
C
B
6
HOLES A: 8.0mm DIAMETER
HOLES B: 6.0mm DIAMETER
HOLES C: 2.0mm DIAMETER (locating holes for switches)
HOLES D: 3.0mm DIAMETER (countersunk)
ALL DIMENSIONS IN MILLIMETRES

Fig.7: if you use a box with a clear lid, then you only have to drill round holes, as shown here. You can stick masking tape on your panel, measure and mark the hole dimensions, or simply copy/print this diagram, cut it out and use it as a template. For the neatest result, countersink the holes marked D on the outside of the panel.

since these will fit a wide variety of shaft types.

There remains the internal wiring to the various switches and connectors on the enclosure. This is relatively straightforward, and shown in the photographs (refer to Figs.3-6).

Programming the micro

I wrote the control software using BASCOM, a BASIC compiler for AVR micros. Having the application and programming notes provided by SiLabs made the code fairly straightforward. Both the .BAS source code and .HEX firmware file are available for download from the July 2022 page of the *PE* website. Note that you might need a paid version of BASCOM to compile the .BAS file – see the box below.

The program header on the board is designed for an AVRISP Mk2 programmer. This can be used in conjunction with the free Atmel (now Microchip) Studio program available for download from: **www.microchip.com**

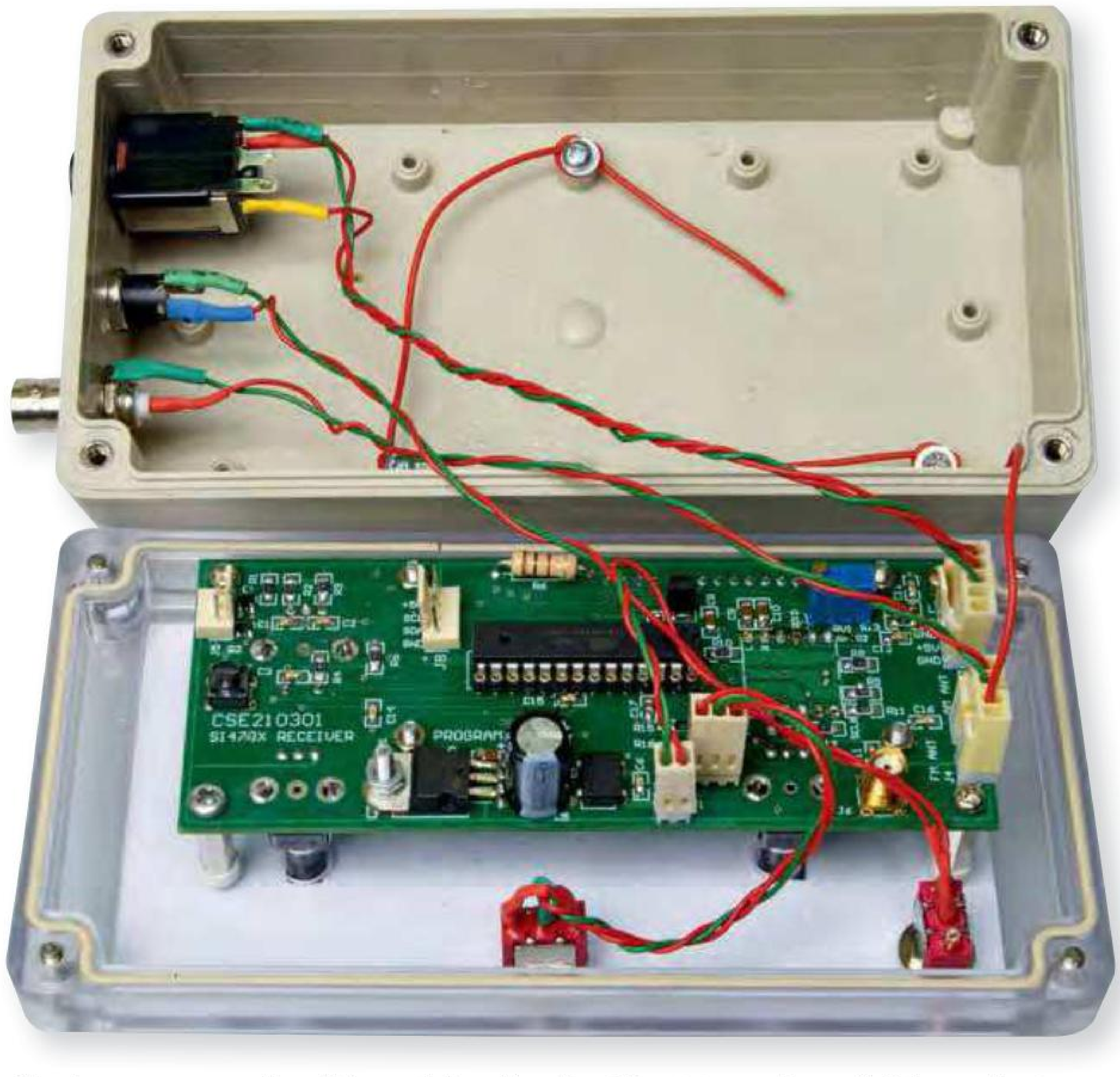
Control of the SiLabs chip is via I^{2}C serial commands, and believe me there are heaps of them. There are all sorts of features, such as scanning, that could be incorporated into the design, but I decided to 'keep it simple, stupid' (KISS). Others might wish to expand on what I have done.

As mentioned above, the pushbutton switch integrated into the tuning encoder toggles through steps to allow fine selection or quick tuning across the band. On the AM band, the step is 1kHz, 9kHz or 100kHz. The FM band is 87MHz to 108MHz and has a step of 100kHz or 1MHz.

On the SW band (if used), the step is 1kHz, 10kHz, 100kHz or 1MHz. About half a second after a frequency is selected, it and the step size are stored in EEPROM. This means that on the next power-up, the EEPROM values are read and that frequency selected.

The top line of the 16x2 LCD shows the frequency, and on the AM and SW bands, it also shows the bandwidth. The second line shows the step size and the signal-to-noise ratio (SNR). The Si chip is sampled once a second to update the SNR figure.

However, the Si4730 module does not give SNR readings on the FM band. Weaker signals give mono rather than stereo output as expected.



Similarly, an example of the wiring for the Si4732 version of this project.

Radio source code

We will make the source code available for this project, along with the HEX file.

The firmware was written in BASCOM-AVR, a version of the BASIC language that compiles to native Atmel AVR code. So it is quite easy to modify.

BASCOM is commercial software; there is a free demo version available which can produce binaries up to 4KB in size, but the radio software is larger than that. A full license for the software costs around £100 (it's available from a few different online shops). But, do note this is only relevant for those who wish to edit the software. You do not need it to load the HEX file into the chip. There are plenty of free software packages that can do that, like MPLAB IPE and AVR Studio.

Parts List – Silicon Labs AM/FM/SW Radio

1 double-sided PCB coded CSE210301C, 123 x 49.5mm available from the *PE PCB Service*
1 9V AC plugpack with 2.1/2.5mm ID barrel plug
1 plastic box with clear lid **[eg, Altronics H0326, Hammond RP1175C: Digi-Key; Mouser]**
1 panel label, to suit version being built
1 16x2 alphanumeric LCD module with blue backlight (LCD1)
1 28-pin narrow DIL IC socket
3 2-pin polarised headers with matching plugs and pins (CON1-3) **[Jaycar HM3412/02, Altronics P5492/72 + 2x P5470A]**
1 5-pin polarised header with matching plugs and pins (CON4) **[Jaycar HM3415/05, Altronics P5495/75 + 5x P5470A]**
2 3-pin polarised headers with matching plugs and pins (CON5, CON7) **[Jaycar HM3413/03, Altronics P5493/73 + 3x P5470A]**
1 4-pin polarised headers with matching plugs / pins (CON8; **optional) [Jaycar HM3414/04, Altronics P5494/74]**
1 panel-mount BNC socket **[Jaycar PS0658, Altronics P0516A]**
1 PCB-mount DC barrel socket, 2.1/2.5mm ID, to suit plugpack **[eg, Jaycar PS0522/4, Altronics P0620/1A]**
1 panel-mount stereo 6.35mm jack socket **[eg, Jaycar PS0182, Altronics P0065]**
1 16-pin low-profile machine pin header strip with matching socket strip (for LCD) *
1 10kΩ multi-turn trimpot (VR1)
2 10kΩ 9mm vertical potentiometers with D-shafts (VR2, VR3) **[eg, Bourns PTV09A-4030F-B103-ND; or use Altronics R1946 with a fluted shaft]**
1 vertical rotary encoder with D-shaft and integrated pushbutton switch (RE1) **[eg, Bourns PEC11R-4225F-S0024]**
3 small or medium-size knobs to suit VR2, VR3 and RE1
1 PCB-mounting small tactile pushbutton switch (S1) **[eg, Jaycar SP0601 or Altronics S1120]**
1 SPDT miniature toggle switch with solder tags (S2) **[eg, Jaycar ST0335]**
1 400µH ferrite rod antenna (L1) **[eg, Jaycar LF1020]**
4 9mm untapped spacers (for LCD mounting) **[Jaycar HP0862, Altronics H1362]**
4 9-10mm-long M3 panhead machine screws and nuts (for REG1)
4 12mm-long M3 countersunk head machine screws
4 6mm-long M3 panhead machine screws
4 12mm-long M3 tapped spacers
4 6mm-long untapped spacers, 3.25mm inner diameter
4 15mm-long M2.5 panhead machine screws and nuts (for LCD mounting)
various lengths of medium-duty hookup wire
various short lengths of heatshrink tubing to suit wire size
* *some options include Semtronics SBU400Z (header) + MH1S19-140 (socket), Mouser 200-BBL116GF (header) + Mouser 200-SL116T10 (socket), element14 1667454 (header) + Jaycar PI6470 (socket) or Altronics P5400 (socket)*

Semiconductors
1 ATmega168 or ATmega328 8-bit microcontroller programmed with CSE210301.HEX (IC2)
1 5V rail-to-rail op amp, SOIC-8 (IC3) [eg, LME49721, available from Digi-Key, Mouser, eBay, AliExpress]
1 7805 5V 1A linear regulator, TO-220 (REG1)
1 LM2936-3.3 3.3V low-dropout linear regulator, TO-92 (REG2)
2 2N7002 small-signal N-channel MOSFETs, SMD SOT-23 package (Q1,Q2)
1 DB104 bridge rectifier (BR1) **[Jaycar ZR1308]**
1 LL4148 small-signal diode, SMD DO-80 MELF (D1) **[Jaycar ZR1103]**

Capacitors (all SMD M2012/0805 size unless otherwise stated)
1 1000µF 16V through-hole radial electrolytic
5 100nF 50V X7R ceramic
2 100µF 6V SMD tantalum, SMA size
5 10nF 50V X7R ceramic
3 10µF 6V SMD tantalum, SMA size
1 1nF 50V X7R ceramic
2 470nF 50V X7R ceramic
2 100pF 50V C0G/NP0 ceramic
3 220nF 50V X7R ceramic
1 47pF 50V C0G/NP0 ceramic

Resistors (all 1% SMD M3216/1206 size unless otherwise stated)
4 100kΩ
2 33kΩ
2 22kΩ
7 15kΩ
3 1kΩ
1 100Ω 5% 2W axial

Additional parts for the Si4732-based version
1 Si4732 IC, SOIC-16 (IC1) [AliExpress, eBay]
1 on-off-on (centre off) miniature toggle switch with solder tags (S3) **[eg, Jaycar ST0336]**
1 32,768Hz watch crystal (X2)
1 100nF 50V X7R ceramic capacitor, SMD M2012/0805 size
2 22pF 50V C0G/NP0 ceramic capacitors, SMD M2012/0805 size

Additional parts for Si4730 module-based version
1 Si4730 module, surface-mounting, with six pads on either side of module's PCB (MOD1) [AliExpress, eBay]
1 SPDT miniature toggle switch with solder tags (S3) **[eg, Jaycar ST0335]**

Optional parts
1 vertical SMA socket (CON6) (external AM antenna input)
1 2x3 pin header (CON9) (for in-circuit programming of IC2)
1 8MHz crystal (X1) (see text)
2 22pF 50V C0G/NP0 ceramic capacitors, SMD M2012/0805 size

UK/EU/US... readers
You don't need to use the exact Altronics/Jaycar parts listed here – they are quoted so you can find local alternatives from the detailed specs provided online by these sellers.

Initial setup

I did not want to have a separate control program for the Si4730 and Si4732 chips, so the chip type is automatically identified on power up. You don't need to do anything.

When I built a second unit, I discovered that the tuning was backwards. Clockwise decreased the frequency! It appears that shaft encoders differ. So I came up with a method to select the correct tuning direction using the existing radio interface. If you find that your encoder action is reversed, then follow these steps:

1. Turn the Bandwidth knob fully clockwise.
2. Tune the AM band to 500kHz. The display will show 'Toggle Direction' on the top line, and 'Direction 1' or 'Direction 2' on the lower line. You don't need to press the button, as it automatically selects the alternative direction when you access this display.
3. Tune to another frequency – make sure the tuning direction is correct.

This setup only needs to be done once, as the parameters are stored in EEPROM and restored on power-up.

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Model Railway Level Crossing

WWW.XSAVA.XYZ &
WWW.SPICYMAGS.XYZ

BY LES KERR

This scale-model Railway Level Crossing has realistic moving barriers, flashing lights and a bell sound recorded from a real level crossing. It can be triggered automatically when a model train approaches. It's controlled by a couple of low-cost PIC microcontrollers and can be built for a modest sum, assuming you have some basic model-making and electronic assembly skills.

During the recent COVID-19 lockdown, I decided to build a model railway layout in OO gauge. As time went on, I added buildings, a tunnel, a bridge, a pond and many other items, including a level crossing. This level crossing can be triggered manually, or automatically when the train passes It includes arms that automatically lower and raise, flashing lights and a realistic bell sound (video at: **siliconchip.com.au/Videos/Level+Crossing**).

This article describes how you can build your own level crossing just like mine.

OO scale is 4mm:1ft which works out to 1:76.2. I applied this scaling to images of signs taken from full-sized crossings. For other items, like the red flashing lights, servos, barrier, and posts, I used slightly bigger parts than the scaled-down real-life items. The bell sounds were recorded from an actual crossing.

The *Level Crossing* project involves building two boxes with posts that sit on either side of the railway tracks where a road meets them. When the train approaches, they drop their arms to block vehicles from crossing the tracks while simultaneously flashing their lights and sounding alarm bells. Once the train has passed, the lights and bells turn off, and the arms lift up again.

Initially, the arms/gates opened and closed at a speed determined by the servo motor manufacturer. This speed was excessive compared with the real-life version, so I developed a circuit to move the arms in small steps, with a delay between each.

The easiest way to do this was to use an inexpensive microcontroller programmed to produce the correct number of steps, with a delay between each, covering the angle that the arm needs to move through.

There are four red LEDs on each post: two facing each way, and they flash alternately in pairs (with the LEDs connected back-to-back illuminated together).

Due to the alternate flashing, normally you would need three wires to connect them up – one to each LED and one common to both. But the hollow post is so small that it is only possible to fit one wire up the centre; using the brass post itself as a conductor gives just two wires.

The way around this is to put the pairs of LEDs to be illuminated together in series, then connect those pairs in inverse parallel. This way, if a current is applied across the set of four LEDs in one direction, two are illuminated, and if the current flow direction is reversed, the other two are illuminated.

The only problem with this is that to illuminate all the LEDs you need a 'full bridge' type of driving arrangement that can drive one end of the LEDs high while it drives the other low, or vice versa. Luckily, this is easily achieved with a pair of microcontroller digital output pins.

Circuit description

Refer now to Fig.1, the *Level Crossing* circuit diagram. It is based mainly around two PIC12F617 8-pin, 8-bit microcontrollers.

When the start switch (S1) is closed, digital input GP2 on IC1 (pin 5) is taken high. The resistor and capacitor help to debounce the switch contacts.

In response, IC1 brings its GP4 digital output high (pin 3), switching on MOSFET Q1, which applies 5V to the recording/playback chip (IC3) with the bell sound recorded on it. IC3 is wired in the continuous mode by connecting pin 2 to pin 13, which results in the bell crossing sound being produced constantly from the connected 8Ω speaker.

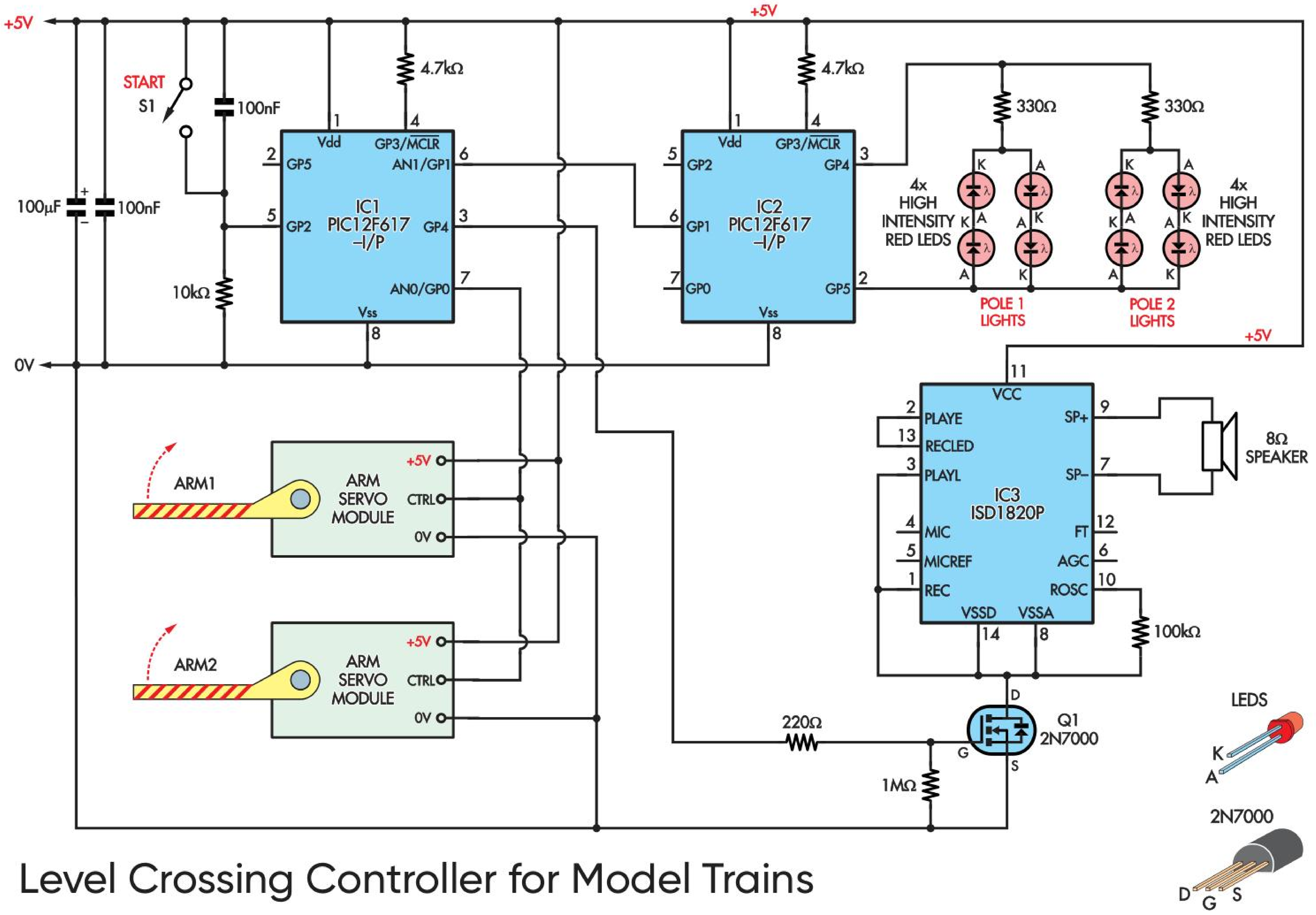


Fig.1: circuit diagram for the Level Crossing Controller. This project uses two PIC12F617 ICs, which saves on extra components – for example, a 555 timer and some transistors that would be needed to flash the LEDs.

The sound continues until Q1's gate is brought low by microcontroller IC1, switching it and the playback module off.

I was going to use a 555 timer to flash the LEDs, but the two-wire requirement meant that I would have to add extra transistors. An inexpensive microprocessor fits the needs perfectly, hence IC2. It probably would have been possible to build this function into IC1, but that would make the timing tricky as IC1 also has to generate servo pulses with accurate timing. A separate chip makes that easy.

At the same time as GP4 goes high, IC1 also brings its digital output GP1 high, which indicates to IC2 to start flashing the LEDs alternately. IC2's digital pins GP4 and GP5 are configured as outputs. Initially, GP4 is taken low and GP5 high, resulting in two of the LEDs on pole one and two on pole two glowing red.

Half a second later, GP4 goes high and GP5 low, causing the LEDs that were lit to extinguish and the other LEDs to light. This sequence is repeated until the start switch opens and IC2's pin 6 input (GP1) goes low again.

Shortly after the lights and bells are triggered, IC1's GP0 digital output produces a series of pulses that go to the servos, causing them to move the arms slowly down until the servo arm is horizontal. It remains down until a couple of seconds after the start switch opens (at which point the flashing lights and bells cease), resulting in the arms moving up slowly to their full upright position.

Switch options

The original design uses a toggle switch for S1, with the *Level Crossing* operated manually. The operator simply switches it on when the train approaches the crossing and switches it off after the train has passed through.

However, some constructors may hanker after automatic operation. This can be achieved by gluing a strong magnet somewhere on the train floor, then positioning two reed switches at strategic points underneath the track. They must be positioned so that the magnet passes over one before the train reaches the level crossing, and the other after it has finished passing through.

Ideally, the magnet should be underneath the train so that it passes as close to the tracks as possible without actually hitting them. However, with a strong enough magnet, you might get away with fitting it inside one of the carriages.

Be careful not to place the magnets right next to the reed switches, as this could demagnetise the switches, making them useless.

An alternative version of the firmware for IC1 (ending in B) changes the function of pin 5 on IC1 to toggle the *Level Crossing* on and off each time that pin transitions from a low to a high level. Therefore, wiring both reed switches across the S1 terminals will provide the required behaviour.

If you have more than one set of tracks going through the level crossing (eg, trains going in both directions), you could wire more than two reed switches in parallel. However, note that odd things will happen if you have trains passing through the crossing in both directions at once.

If you want to support that case properly, you will need to develop a small external circuit that handles the logic to trigger this circuit, and you'll probably want to stick with the A firmware in that case. The logic could consist of two S/R flip-flops with their outputs wired through an OR gate, going into pin 5 of IC1.

Note that the B firmware could also be used with a momentary pushbutton type switch wired across S1, to allow the operator to manually toggle it on and off if desired.

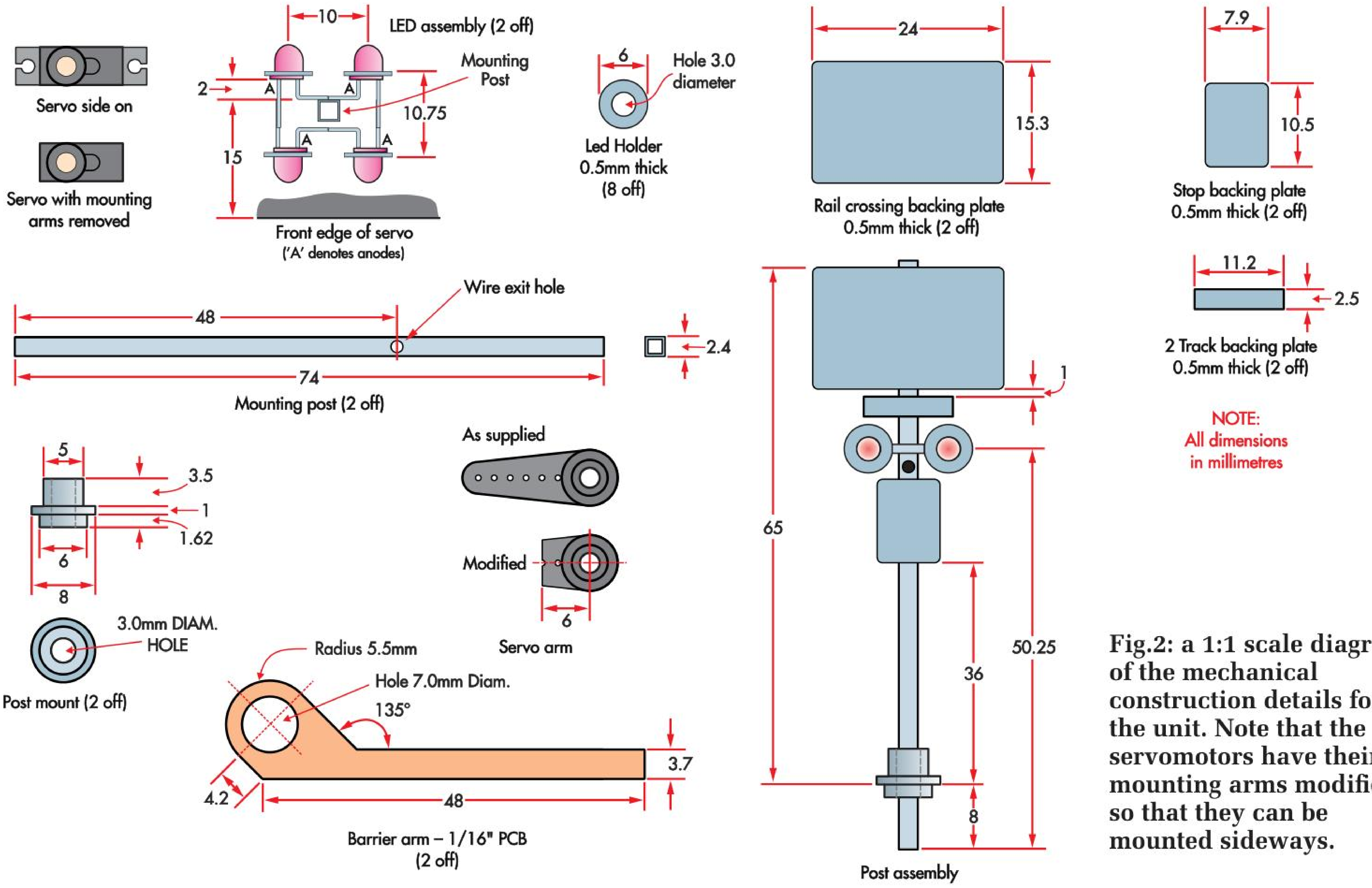

Servo side on
Servo with mounting arms removed
10
LED assembly (2 off)
Mounting Post
2
A
A
A
A
10.75
15
Front edge of servo
('A' denotes anodes)
6
Hole 3.0 diameter
Led Holder 0.5mm thick (8 off)
24
15.3
Rail crossing backing plate 0.5mm thick (2 off)
7.9
10.5
Stop backing plate 0.5mm thick (2 off)
11.2
2.5
2 Track backing plate 0.5mm thick (2 off)
NOTE: All dimensions in millimetres
Wire exit hole
48
74
2.4
Mounting post (2 off)
1
65
50.25
36
8
Post assembly
5
3.5
1
1.62
6
8
3.0mm DIAM. HOLE
Post mount (2 off)
As supplied
Modified
6
Servo arm
Radius 5.5mm
Hole 7.0mm Diam.
135°
3.7
4.2
48
Barrier arm – 1/16" PCB (2 off)

Fig.2: a 1:1 scale diagram of the mechanical construction details for the unit. Note that the servomotors have their mounting arms modified so that they can be mounted sideways.

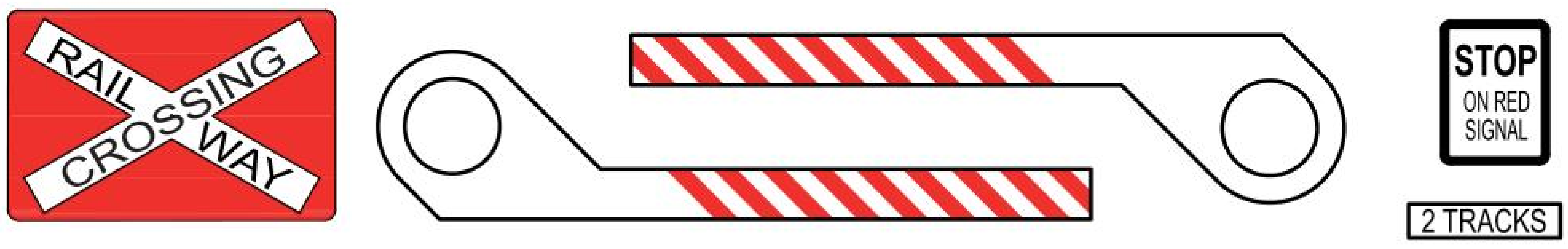

RAIL
WAY
CROSSING
STOP
ON RED
SIGNAL
2 TRACKS

Fig.3: the label artwork for the various parts of the Railway Level Crossing. This is shown at actual size and can be downloaded from the July 2022 page of the PE website.

Construction

There are two main parts to the construction: the electronic assembly, which is pretty straightforward, and the fabrication of the boxes, poles, arms and other pieces that make up the level crossing, which generally will take longer. As it is most of the work, we'll start with the mechanical assembly.

The mechanical parts drawing (Fig.2) shows the dimensions and quantity of the parts to build the crossing. I will go through each piece and describe how I made them.

Mounting post

This was made from a length of hollow square brass 3/32-inch (about 2.4mm) extrusion. Mine was made by K&S metals, which most model shops stock. You have to drill a 1.5mm hole 48mm from the bottom as the exit hole for the LED power wire. Using a small round file, clean up the hole and the ends so that all burrs are removed that might cut the insulation on the wire.

Backing plates

There are six of these, all made from 0.5mm brass sheet, also from K&S metal. You will need two of each of the rail crossing backing plates, track backing plates and stop backing plates. Using a small metal saw, cut out the required size and then use a file to round the edges and remove any burrs.

Barrier

You will need two; I made them from 1/16-inch (1.6mm) blank PCB scraps. You can draw up the shape on the PCB or trace the shape from the label. Drill the 7mm hole and cut the barrier from the PCB using a saw and file.

LED holder

I turned these up on a lathe by bolting eight square pieces of 0.5mm-thick brass together on a mandrel, each with a 3mm hole in the centre.

Alternatively, buy some brass washers with a 3mm centre hole (the LED diameter) and an outside diameter of about 6mm (not critical). If the inner hole is slightly larger than 3mm, you can hold the LED in place using glue. The washers should be painted matte black.

Post mount

This is an *optional* part that adds a bit more realism. Because the base of my model railway was made of polyurethane, I had to insert a metal plate under the rails to which the crossing parts were mounted. I drilled a 6mm hole in the plate and held the post mount in place with Loctite. It's a simple turning job to make the part out of aluminium round.

Servo arm

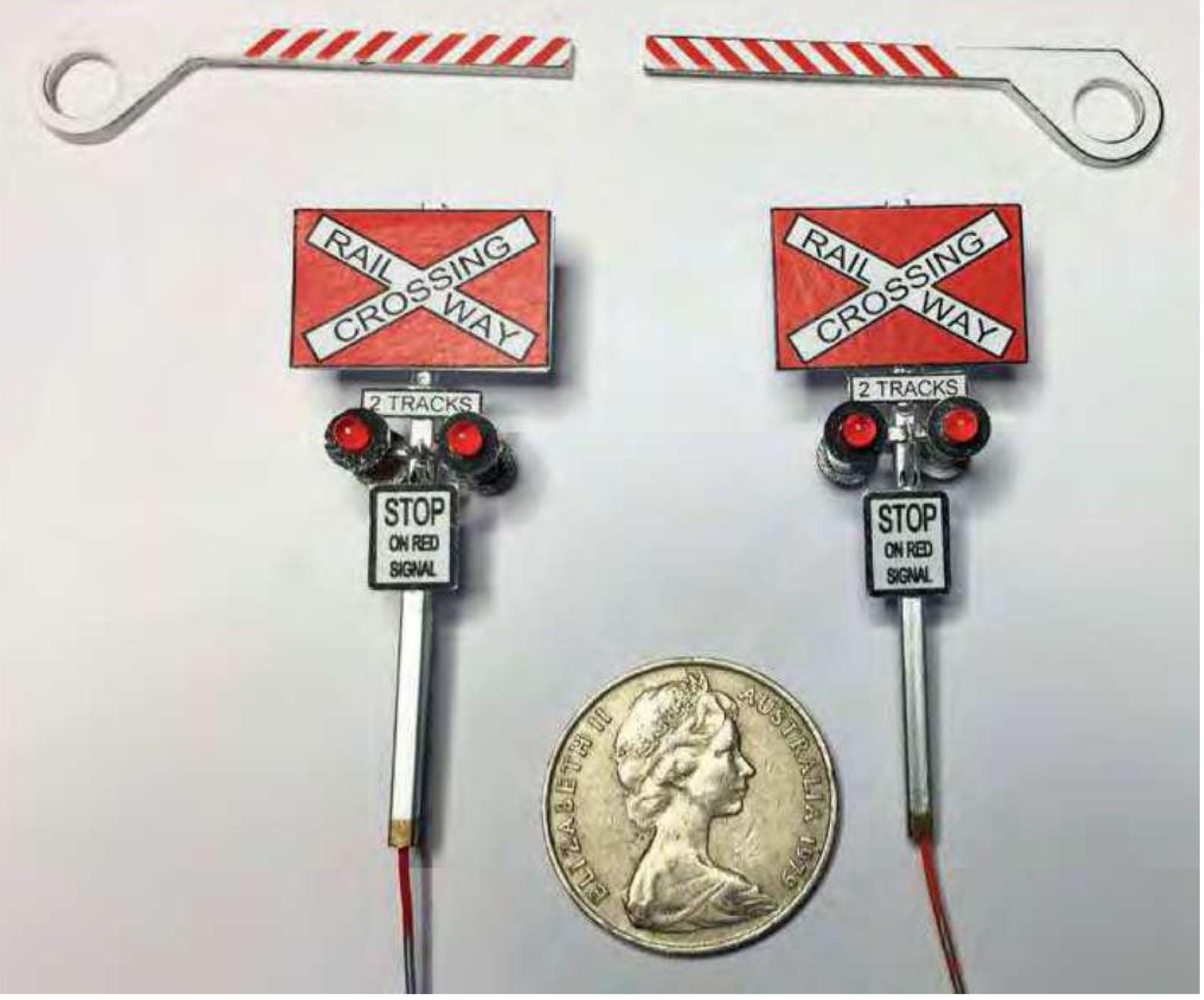
The miniature servo is supplied with a servo arm that has to be cut to size. The mechanical drawing shows the arm before and after modification – you need two, one for each barrier. The barrier is glued to this part of the assembly, as described later.

LED assembly

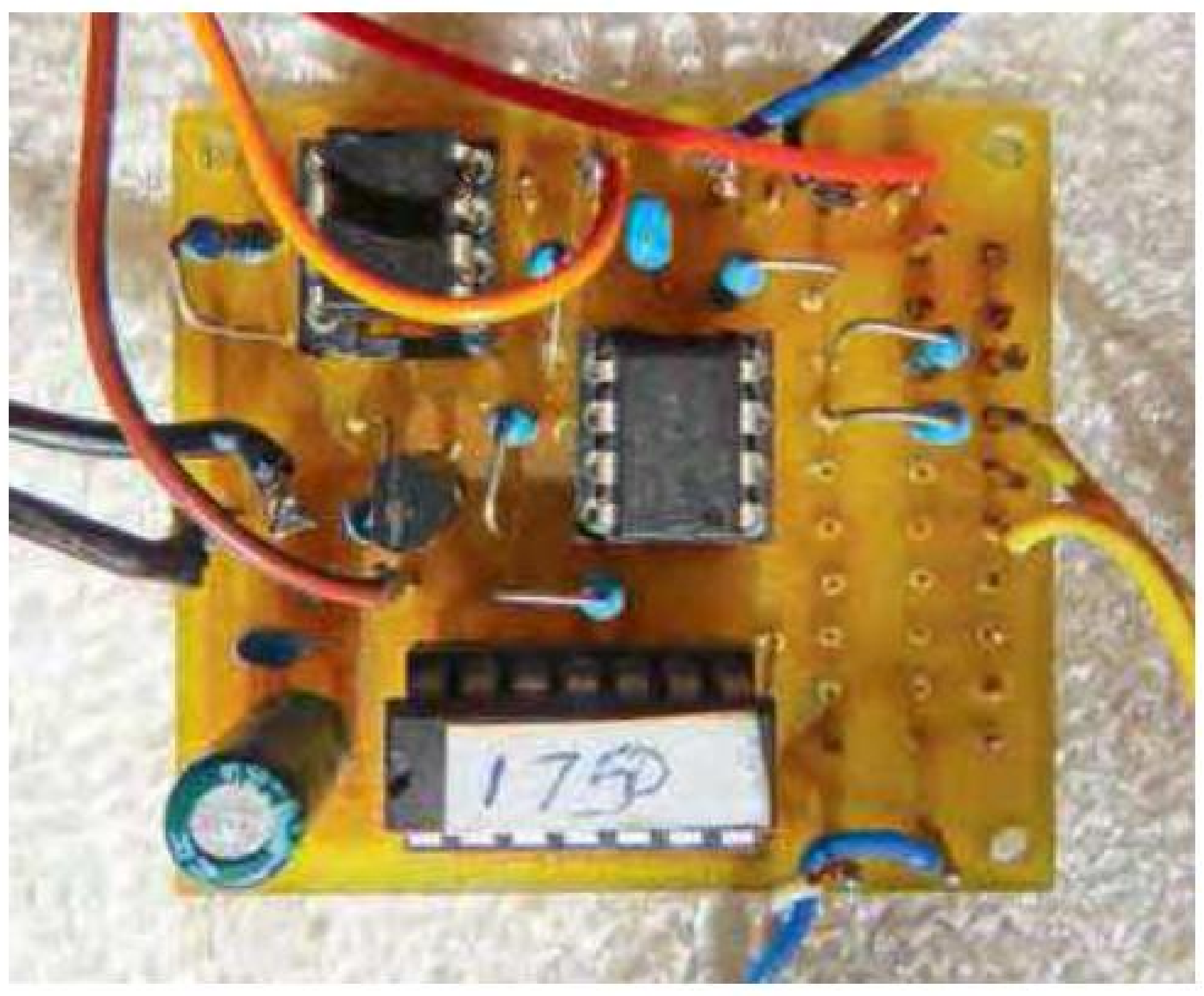
Make two LED assemblies, as shown in Fig.2. Use pliers to bend the leads so that you put limited stress on the LED connections. Cut the leads to size and solder them together. The anodes of the LEDs are marked with 'A' on the drawing. At this stage, don't solder it to the post.

Servos

So that the servomotors can be mounted on their sides, it is necessary to remove the mounting arms. Use a hacksaw to cut them to the size shown on the drawing.



An example of what the finished barrier and railway crossing sign looks like.



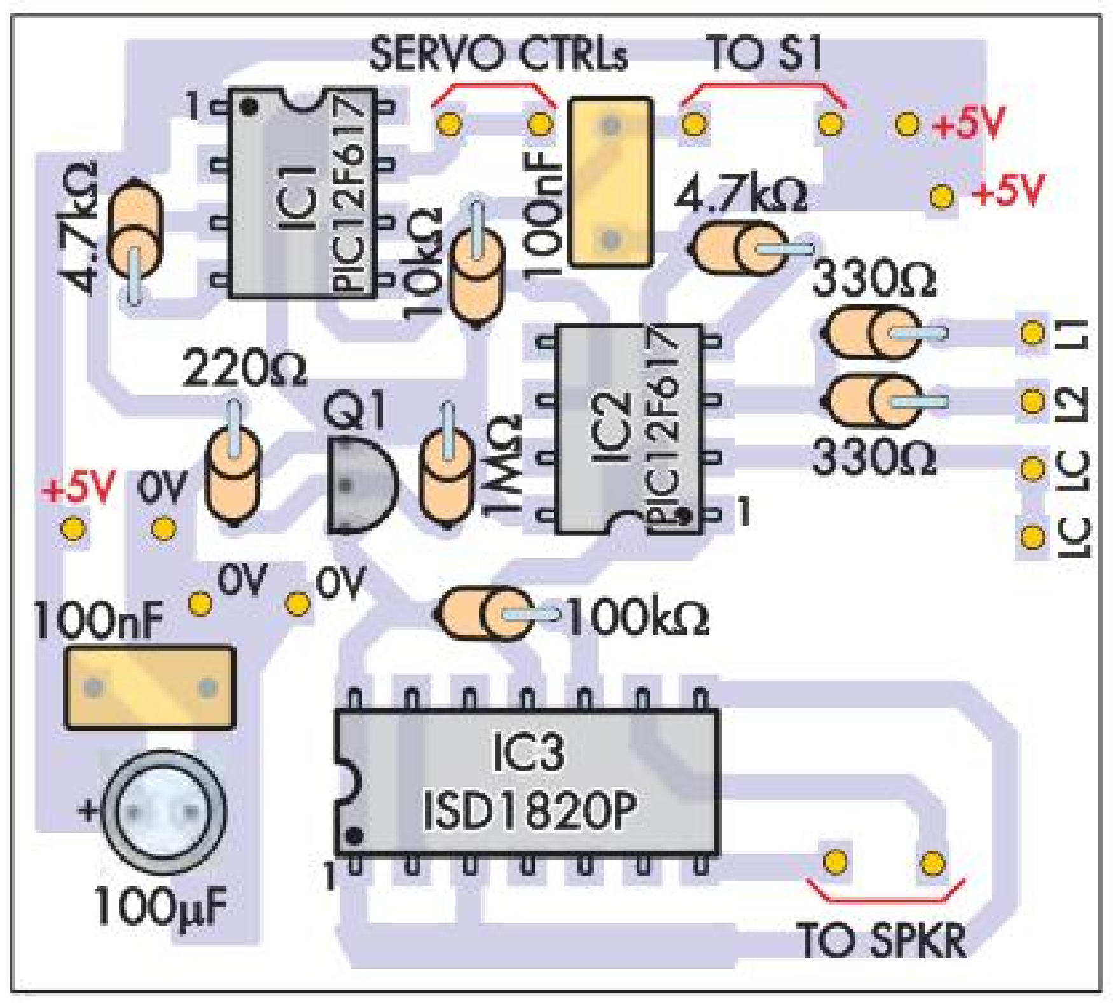


Fig.4: the overlay diagram for the Level Crossing. Note the resistors are mounted vertically.

Sign labels

Fig.3 shows the three sign labels and the covering for the barrier. To make these, download the 1:1 scale label drawing as a PDF from the July 2022 page of the *PE* website and use a colour printer with 80gsm paper.

Print the drawing and measure the 100mm line. Let's say it measures 99mm. This gives a calibration factor of 100/99 = 1.01 or 101%. So if you print the file again at 101% scale, the 100mm line should measure 100mm.

Mechanical parts assembly

The first step is to push the black LED holders over the LEDs. Next, with the mounting hole at the rear of the post, clean a 2mm strip on the front with a centre 50.25mm from the bottom and tin that strip with solder.

Place the LED assembly over the post, as shown in the drawing. Using a soldering iron, attach it to the post. Select about 100mm of thin wire with high-temperature insulation and slide it into the hollow post at the bottom until it exits out at the 1.5mm hole, 48mm up. Strip off about 2mm of insulation and solder it to the LED assembly as shown in the upper left photo.

The three backing plates are then glued to the post as shown, using Loctite GO 2. Leave it for 24 hours for the glue to set. Using heatshrink tubing and masking tape, cover the LEDs and then spray the assembly with aluminium-coloured paint. When dry, remove the heatshrink tubing and masking tape and attach the three labels to their respective backing plates.

The final task is to connect the second power lead to the post on the two post assemblies. This is done after they are assembled on the crossing, as any solder on the post would stop it from going into its mounting hole.

Again, clean and tin a 2mm section at the bottom end of the post and attach a wire to it. I will leave the design of the road across the track up to you, as the sizes will depend on your particular railroad layout. Mine consisted of timber wedges painted matte black.

Electronic assembly

The heart of the level crossing circuit is built on a single-sided PCB coded 09108211. It is available from the *PE PCB Service* and measures 48 x 43mm. The PCB overlay diagram (see Fig.4) can be used as a guide during construction. Start by fitting the PCB pins, then the IC sockets. We used IC sockets for the microprocessors and the recording ICs in case we ever wanted to reprogram or change the sound. Do take care to orient them correctly.

Now add the resistors, which are mounted vertically, followed by the capacitors. Check that the 100µF capacitor is the right way round. Next, add the 2N7000 MOSFET Q1, oriented as shown.

The wiring diagram (Fig.5) shows how to connect the two post assemblies, the loudspeaker, the trigger

RAIL WAY CROSSING
2 TRACKS
STOP ON RED SIGNAL

Here is an example of the completed project fitted onto a model railway track.

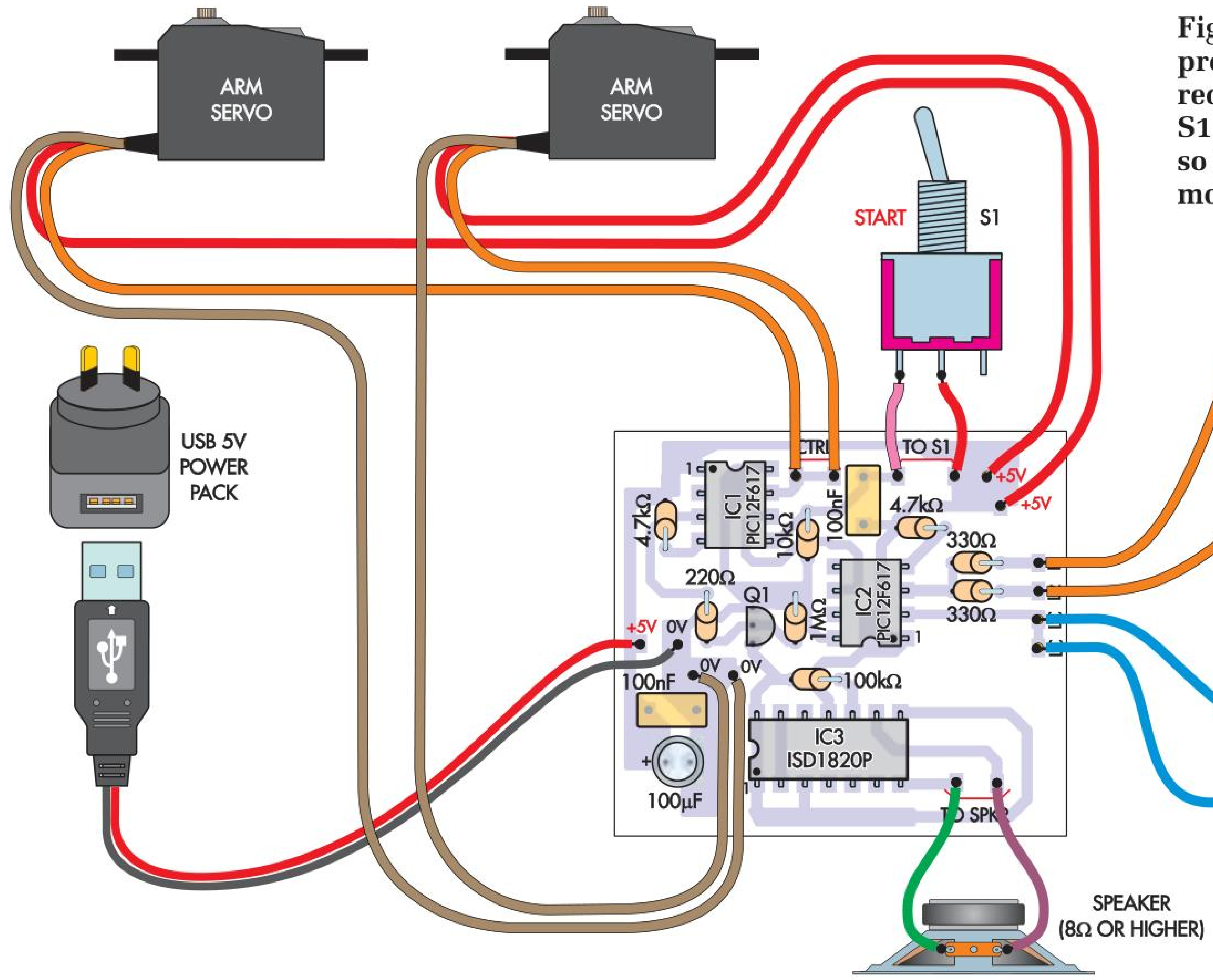

ARM SERVO
ARM SERVO
START
S1
USB 5V POWER PACK
POLE 1 LEDS
POLE 2 LEDS
CTRL
TO S1
+5V
+5V
1
IC1 PIC12F617
4.7kΩ
10kΩ
100nF
4.7kΩ
330Ω
330Ω
220Ω
Q1
1MΩ
IC2 PIC12F617
1
+5V
0V
0V
0V
100nF
100kΩ
IC3 ISD1820P
+
100µF
TO SPKR
SPEAKER (8Ω OR HIGHER)

Fig.5: the wiring diagram for the project. For triggering the device, we recommend using a reed switch for S1 which is hidden under the tracks, so that it can be triggered by a magnet mounted on the locomotive.

switch and the two servomotors. Rather than using a pushbutton switch as shown, we expect most constructors will use a reed switch hidden under a section of the track, with a magnet on the model locomotive to trigger it before the loco reaches the crossing.

Finally, connect the positive of the 5V power pack to the +5V point on the board and the negative to 0V. Check that all the connections are correct and that there are no dry joints or solder bridges.

At this stage, don't plug in the PIC controllers (IC1 and IC2). There is no provision for programming either of the microcontrollers in-circuit, so you will either need to program them yourself using an external programmer (eg, PICkit 3 or 4) before plugging them in.

You can download the HEX files from the July 2022 page of the *PE* website; the file ending in 'A' or 'B' is for IC1 (depending on the type of switch used) and the 'C' file is for IC2.

Recording the bell sound

The download package on our website also includes a WAV audio file of the bell sounds, which you need to transfer to IC3. This is supplied as part of a module that is capable of recording by itself (see the photo opposite). The simplest way to transfer the bell sounds from a computer to the chip is to place the module's microphone close to your computer speakers.

First, though, the module needs a power source. Connect a 5V supply to its power input terminal block. With the green terminal block on the left, make sure that the two slide switches marked FT and repeat are switched to the left-hand side. It's also a good idea to temporarily connect the 8Ω speaker to this module so that you will be able to hear and check what you have recorded.

Hold the module so that its electret microphone is about 100mm from the computer loudspeaker. Play the downloaded WAV file at the maximum reasonable volume, and after it starts, hold down the REC button until LED D1 goes out (after the maximum recording time of about 10 seconds).

Slide the repeat switch to the right and momentarily press the PLAYE button. This should verify that you now have a continuous recording of the level crossing bell sound on the chip.

Testing the electronic assembly

Plug the 5V power pack into the mains and, using a voltmeter, check that you have 5V between pins 1 and 8 on IC1's socket. Switch off the power supply, remove the ISD1820P IC from the recording and playback module and insert it into the *Level Crossing* PCB, oriented as shown in Fig.4. Do the same for the PIC microprocessors, making sure that you don't get them mixed up.

Switch the power on, close the start switch and you should see the red LEDs flashing alternately and hear the level crossing bell sound from the speaker. Half a second later, the servomotors

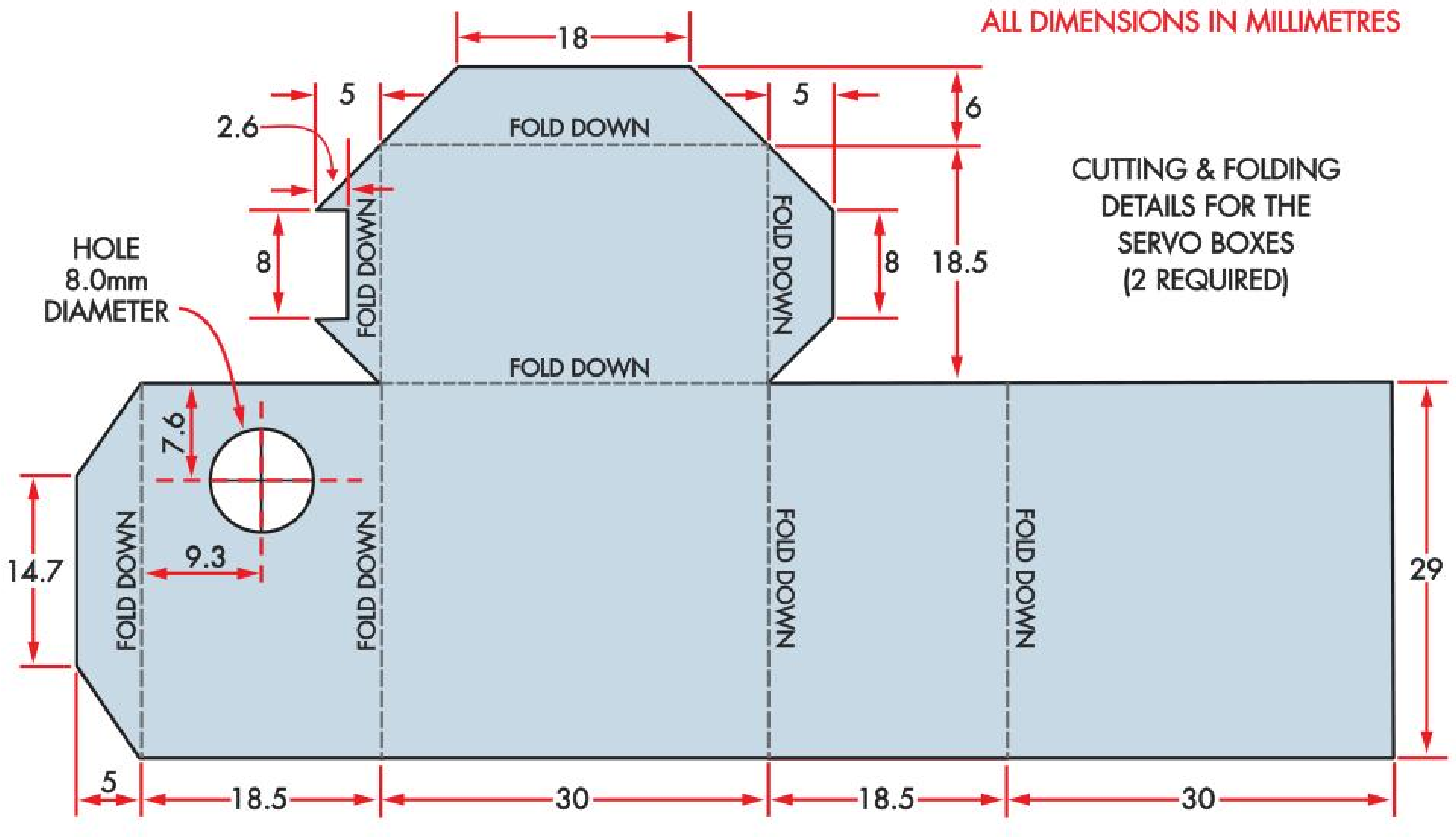
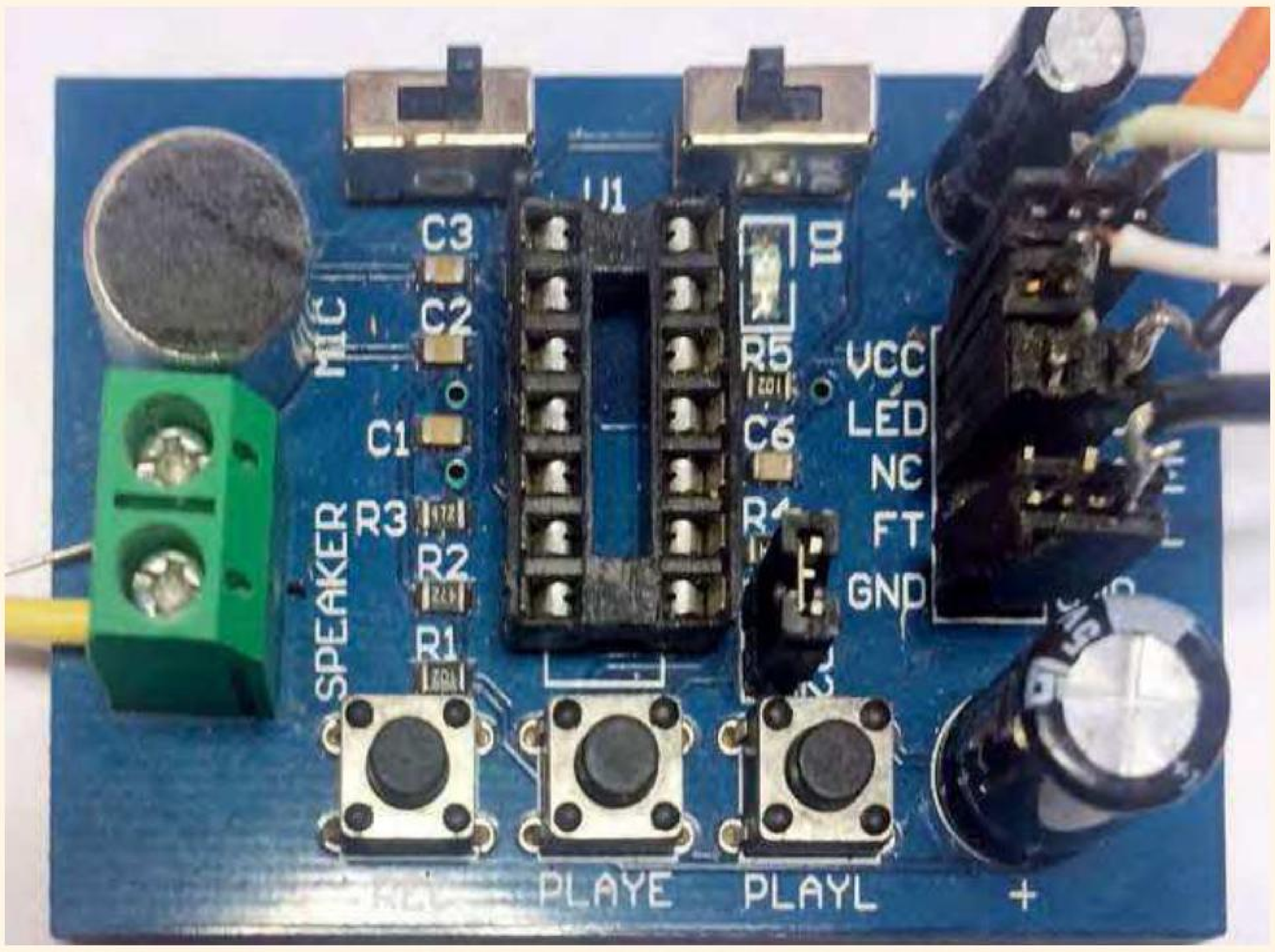

ALL DIMENSIONS IN MILLIMETRES
18
5
5
6
2.6
8
8
18.5
FOLD DOWN
FOLD DOWN
FOLD DOWN
FOLD DOWN
HOLE 8.0mm DIAMETER
CUTTING & FOLDING DETAILS FOR THE SERVO BOXES (2 REQUIRED)
7.6
9.3
14.7
FOLD DOWN
FOLD DOWN
FOLD DOWN
FOLD DOWN
29
5
18.5
30
18.5
30

Fig.6: this box was designed to hide the servomotors when displayed on the track. You can print this diagram on a suitable material, fold it and then paint it if you want.

A more complicated approach to recording the bell sounds



C3
C2
C1
MIC
SPEAKER
R3
R2
R1
U1
D1
R5
C6
R4
VCC
LED
NC
FT
GND
PLAYE
PLAYL
+

The ISD1820P is often sold as a module similar to this. This version is sold by Jaycar (www.jaycar.com.au/p/XC4605). But there are a wide variety of alternatives available online that will also work. Note that they might have different arrangements for feeding in power, jumpers instead of switches and other minor variations. (Do ensure the IC is socket mounted – NOT soldered!)

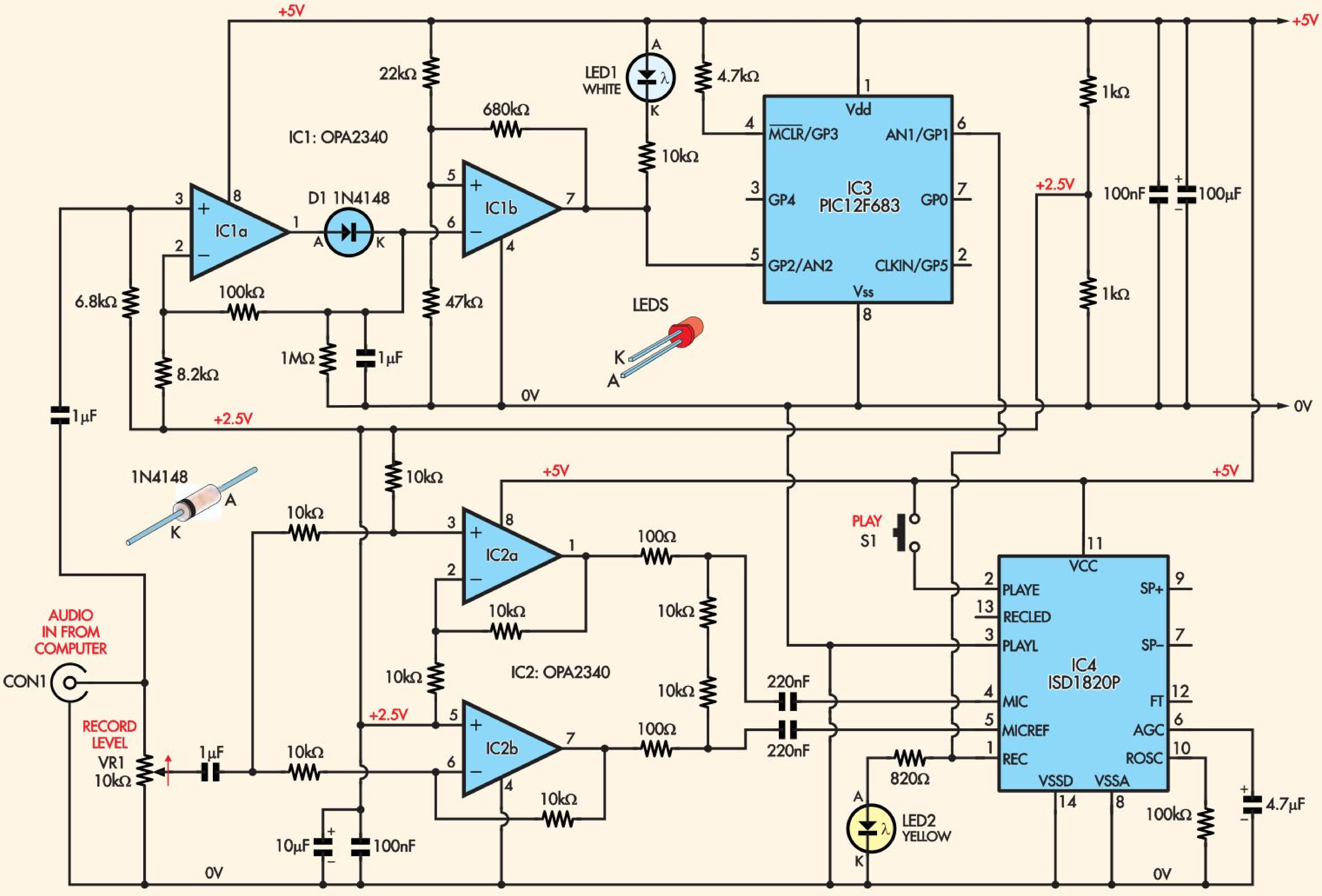
I designed the circuit shown in Fig.7 to provide a more elegant way of recording the bell sounds from a computer onto the ISD1820P chip. However, while it is a better solution, the effort and expense of building this circuit are not worthwhile for a one-off recording. The speaker/microphone method described in the text provides decent results with minimal effort. Regardless, I am presenting the circuit here for those interested.

Audio from the PC's output jack is adjusted in level using VR1, then AC-coupled to two op amps, IC2a and IC2b. These convert the single-ended computer audio into a balanced signal, ideal for feeding to the ISD1820P's balanced microphone inputs at pins 4 and 5.

The components at the top of the circuit detect when the audio playback begins on the computer and automatically triggers recording on the ISD1820P (IC4), so that you don't have to try to press both buttons simultaneously to get the best results.

IC1a amplifies the audio signal by 83 and feeds a diode charge pump (D1 / 1µF capacitor). This capacitor quickly charges as soon as a signal comes from the computer. The other half of the dual op amp, IC1b, is connected as a comparator, pulling the GP2 digital input of IC3 (pin 5) low as soon as the charge on that 1µF capacitor exceeds about 3.3V. This also lights LED1.

When 8-bit PIC microcontroller IC3 detects that its pin 5 has gone low, it generates a pulse from its GP1 digital output (pin 6) to trigger recording mode on IC4. This has an appropriate length to record the whole bell sound sequence. So IC3 is acting as a pulse stretcher.



+5V
+5V
22kΩ
680kΩ
LED1 WHITE
A
K
λ
4.7kΩ
10kΩ
IC1: OPA2340
IC1a
IC1b
D1 1N4148
A
K
6.8kΩ
100kΩ
8.2kΩ
1MΩ
1µF
47kΩ
0V
+2.5V
1µF
LEDS
K
A
Vdd
MCLR/GP3
AN1/GP1
IC3 PIC12F683
GP4
GP0
GP2/AN2
CLKIN/GP5
Vss
1kΩ
1kΩ
+2.5V
100nF
100µF
0V
1N4148
A
K
10kΩ
10kΩ
+5V
IC2a
IC2b
IC2: OPA2340
10kΩ
10kΩ
100Ω
10kΩ
10kΩ
100Ω
220nF
220nF
+2.5V
10kΩ
10kΩ
10µF
100nF
0V
AUDIO IN FROM COMPUTER
CON1
RECORD LEVEL
VR1 10kΩ
1µF
PLAY
S1
+5V
VCC
PLAYE
RECLED
PLAYL
IC4 ISD1820P
MIC
MICREF
REC
VSSD
VSSA
SP+
SP–
FT
AGC
ROSC
820Ω
LED2 YELLOW
100kΩ
4.7µF
0V

Fig.7: a circuit I designed to record sound to the ISD1820P module directly from a computer's audio output jack.

should move slowly clockwise about 70°. On opening the switch, the servomotors should slowly move back, the flashing lights should extinguish, and the bell sound should stop.

Final fitting

Glue the barrier covering labels to each side of each barrier and trim any excess overhang. Mount the servomotors side-on, as shown in the photo.

Apply power and close the start switch. The servomotors will move down to the barrier closed position. Slide the barrier over the modified servo arm bush as shown in the photo, and then attach the servo arm to the servomotor.

Glue the barrier onto the servo arm so that it is horizontal and let it dry. Do the same for the other servomotor. Open and close the switch to check that the barriers operate, as in the video.

To hide the servomotors, I made boxes out of folded card and painted them silver. Fig.6 is the cutting diagram for this box, and it is also available as a PDF download.

Print the 1:1 scale drawing on 80gsm paper – or any suitable material of your choosing – cut out the outline, fold it up into a box and use super glue to hold it together. In this operation, remember to be very careful not to get super glue on your fingers – unsticking them can be painful! Use tweezers to hold the surfaces together when the glue is setting.

Last, Paint the box silver, cut out the hole for the servomotor and then fit the box. (Repeat this build for the other servomotor.)

Parts List – Level Crossing Controller

1 control PCB assembly (see below)
1 5V DC supply (eg, USB charger with USB cable)
1 SPST toggle switch (S1) ***OR***
1 momentary pushbutton switch (S1) ***OR***
2 reed switches plus a magnet (S1; see text)
8 3mm high-intensity red LEDs with diffused lenses (LED1-LED8)
2 1.6kg.cm 9g 180° micro servos [**eg, Core Electronics SER0006**]
1 8Ω speaker [**eg, Jaycar AS3006**]
1 ISD1820P-based audio recording/playback module [**eg, Jaycar XC4605, see text**]
1 set of printed labels (see Fig.3)
various lengths and colours of light-duty hookup wire
various mechanical parts (see Fig.2)

Control PCB parts

1 single-sided PCB coded 09108211, 48 x 43mm
2 8-pin DIL IC sockets (for IC1 and IC2)
1 14-pin DIL IC socket (for IC3)
1 PIC12F617-I/P 8-bit microcontroller programmed with 0910821A.HEX (for toggle switch) ***OR*** 0910821B.HEX (for momentary or reed switches) (IC1)
1 PIC12F617-I/P 8-bit microcontroller programmed with 0910821C.HEX (IC2)
1 ISD1820P audio recording/playback IC with bell sound recorded (IC3) (from module listed above)
1 2N7000 small-signal N-channel MOSFET (Q1)
1 100µF 16V electrolytic capacitor
2 100nF 63V MKT or 50V ceramic capacitors
16 1mm PCB pins

Resistors (all 1/4W 1% axial metal film)

1 1MΩ
1 100kΩ
1 10kΩ
2 4.7kΩ
2 330Ω
1 220Ω

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Teach-In 8 CD-ROM
Exploring the Arduino

This CD-ROM version of the exciting and popular *Teach-In 8* series has been designed for electronics enthusiasts who want to get to grips with the inexpensive, immensely popular Arduino microcontroller, as well as coding enthusiasts who want to explore hardware and interfacing. *Teach-In 8* provides a one-stop source of ideas and practical information.

The Arduino offers a remarkably effective platform for developing a huge variety of projects; from operating a set of Christmas tree lights to remotely controlling a robotic vehicle wirelessly or via the Internet. *Teach-In 8* is based around a series of practical projects with plenty of information for customisation. The projects can be combined together in many different ways in order to build more complex systems that can be used to solve a wide variety of home automation and environmental monitoring problems. The series includes topics such as RF technology, wireless networking and remote web access.

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SOFTWARE

The CD-ROM contains the software for both the *Teach-In 8* and PICkit 3 series.

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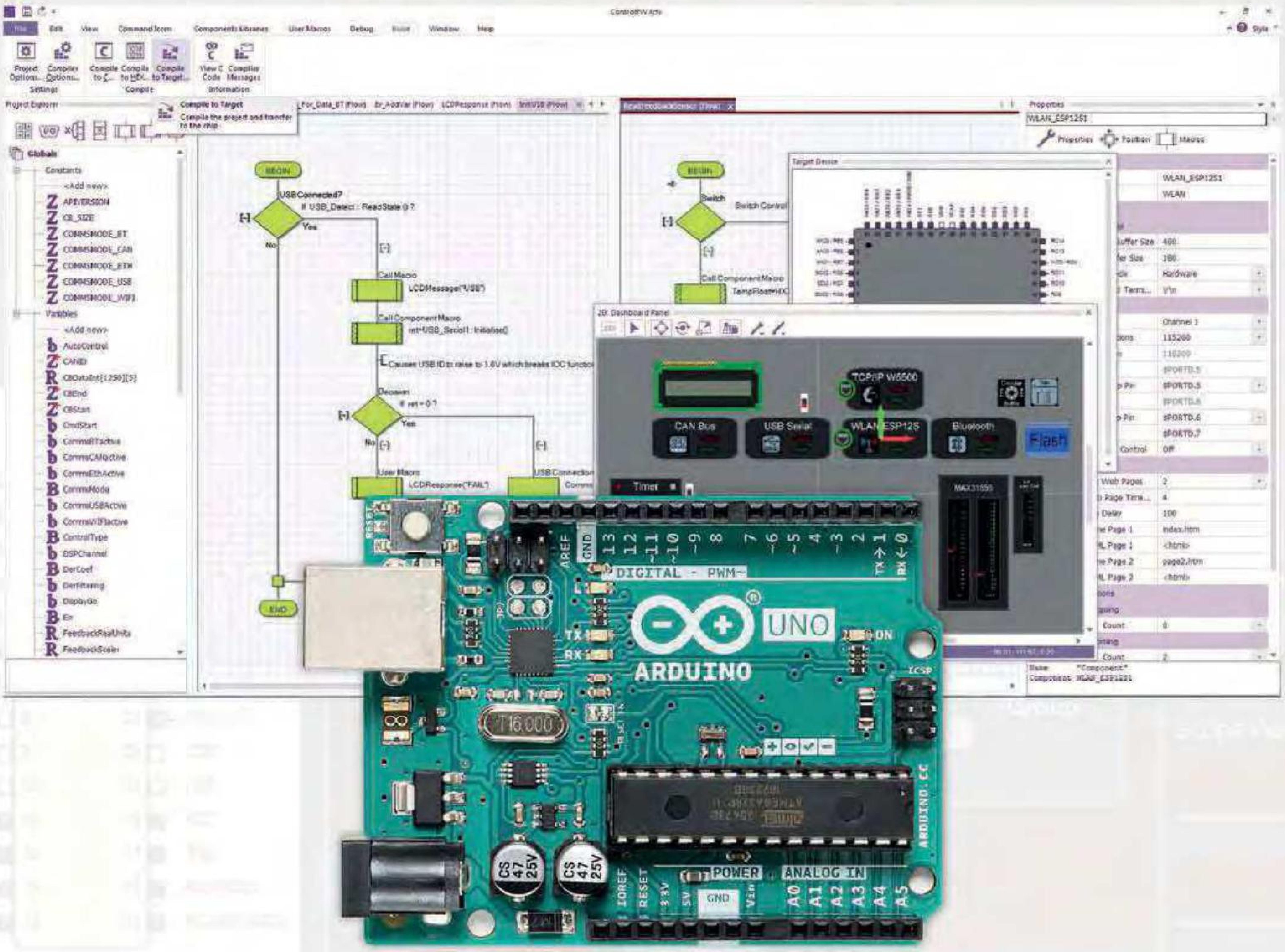

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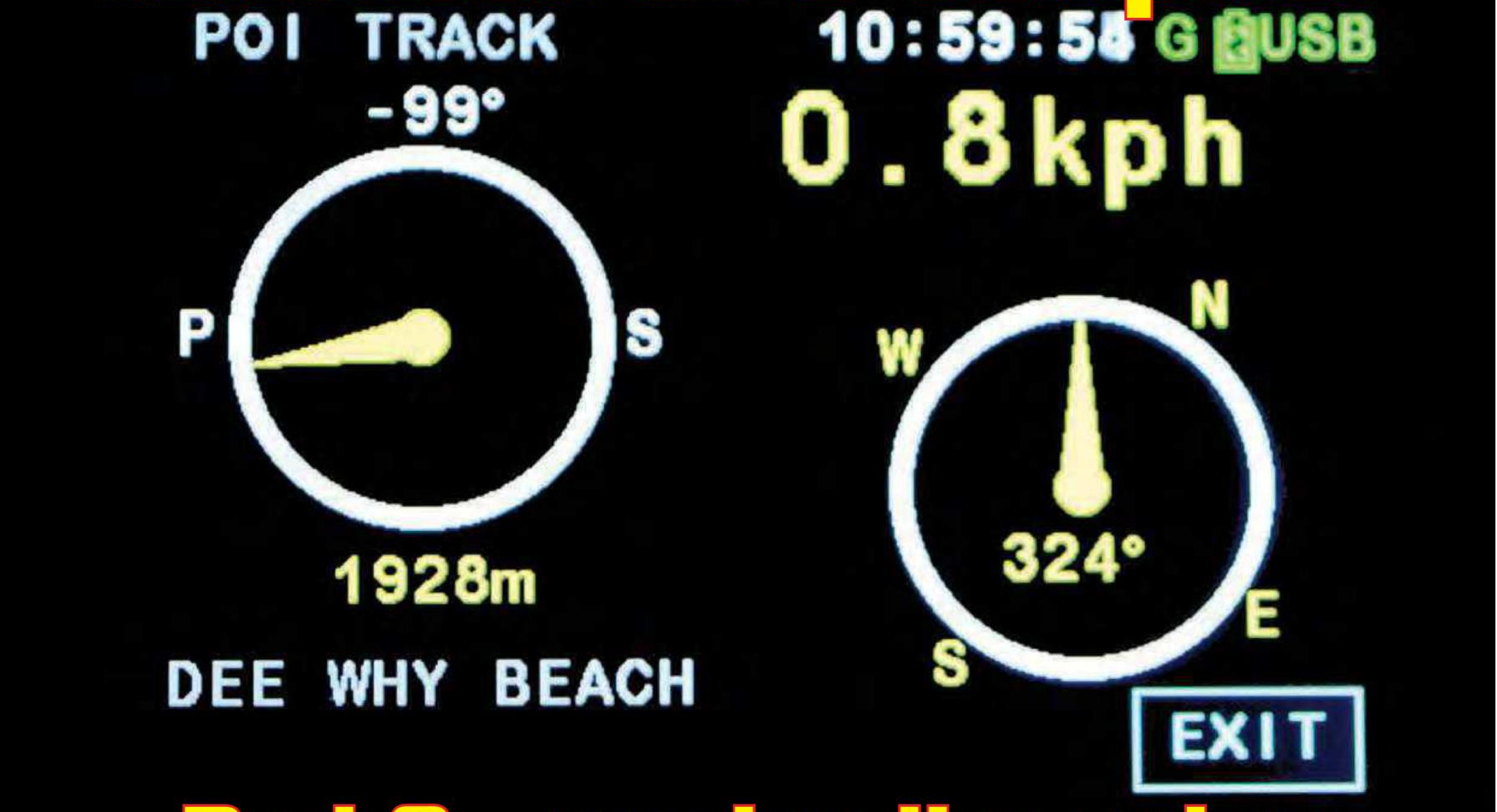
Advanced GPS Computer



Part 2 – construction and use

Our new GPS Computer has host of useful features. In Part 1 we described how it works, so this month we'll move onto the construction and instructions for use. We'll also delve into how the software works, for those who are interested.

by Tim Blythman

We have a lot to cover in this article – after describing the assembly of the custom board, putting it all together and fitting it into its case, we also need to explain how to use its many features.

Since the software is quite complicated and we had to solve some interesting problems to make it work, we also have a separate panel explaining some of the code's trickier details, including the CFUNCTIONs that do most of the hard work. You can read that one if you are interested, or skip it if you aren't. So without further ado, let's move on to putting the *Advanced GPS Computer* together.

Construction

You will need to build the *Micromite V3 BackPack* module with a 3.5-inch LCD touchscreen. Its construction was detailed in the August 2020 issue.

If you haven't already done so, you need to fit the DS3231 RTC IC and its accompanying passive components to the *V3 BackPack* (see photos overleaf). This is a surface-mounting part, so the usual cohort of SMD gear will be required. There are also a few SMDs on the *GPS Computer* PCB.

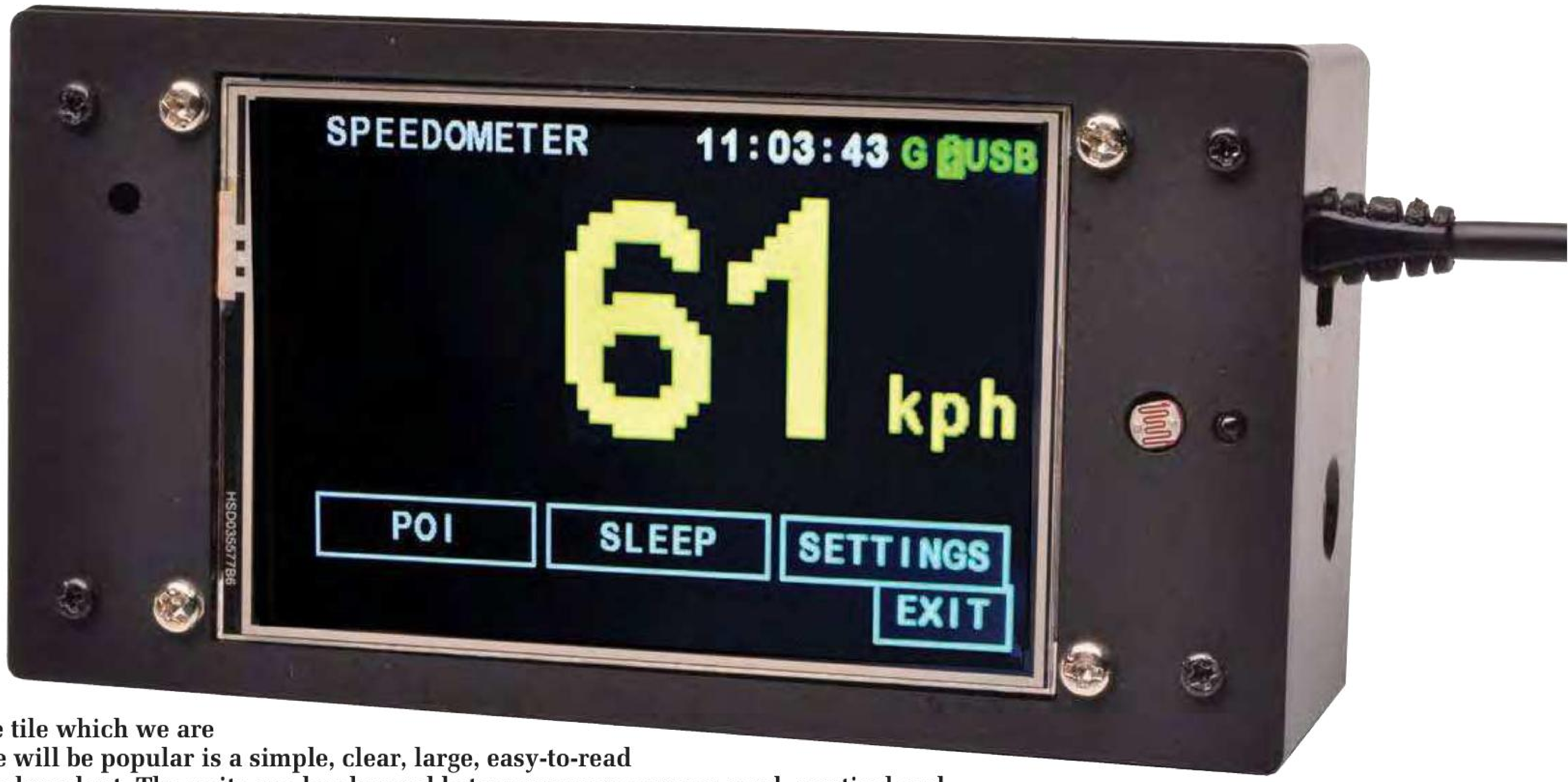
A fine-tipped temperature-adjustable soldering iron is highly recommended, along with fine solder wire, flux paste, tweezers, a magnifier and solder-removal wicking braid. The flux releases smoke when soldering, so good ventilation and/or fume extraction is needed.

Start by applying flux to the pads for the DS3231, then carefully tack one lead in place, ensuring that its pin 1 matches the dot marked on the PCB. If necessary, adjust its position to centre the chip on its pads and ensure it is sitting flat on the PCB, then solder the remaining pins.

Remove any bridges between pins by applying extra flux and then pushing the braid against the bridge with the iron. Allow it to draw up the excess solder before carefully pulling it away. Fit its bypass capacitor next, followed by the two resistors, and trim their leads short.

When fitting header socket CON9, ensure it is placed on the PCB's underside and soldered from the top. Check that it is square and vertical so it will mate properly with the matching socket on the board underneath.

You might like to leave this for later, and line up all the headers at the same time by sandwiching them between



One tile which we are sure will be popular is a simple, clear, large, easy-to-read speed readout. The units can be changed between many common road, nautical and aeronautical options. There's even enough room left over to add a handful of other tiles below this.

the two PCBs for alignment. This will guarantee that the headers will match.

Also make sure to fit female headers to the underside of the *V3 BackPack* for the standard Micromite I/O pin connections.

GPS Computer PCB assembly

Refer to the PCB photos and overlay diagram, Fig.2, during construction to assist with component placement and orientation.

Start with the surface-mounted components on the *GPS Computer* PCB. This includes Q1, Q2, IC3 and IC4. Apply flux to the pads and rest the parts in place.

Take care not to mix up Q1 and Q2. Q1, Q2 and IC4 should only fit one way, but you'll need to check IC3's orientation. Its pin 1 should be towards the centre of the PCB.

Tack one lead of each component and check the remaining pins are flat and square within their pads, adjusting if necessary. Then solder the remaining pins and remove any bridges, as described above for the DS3231 on the *V3 BackPack* PCB.

Once the surface-mounted parts are fitted, clean the PCB with a flux cleaner and allow it to dry before continuing.

Through-hole parts

Continue by fitting the fixed resistors. The values are marked on the PCB silkscreen; check each batch with a multimeter to confirm their values. After soldering, trim the leads close to the PCB so it will fit in the enclosure later.

Fit the two diodes next. The larger 1N5819 type (D1) is near CON2, while the smaller 1N4148 is near CON4. Observe their polarity and match the cathode bands to the PCB silkscreen.

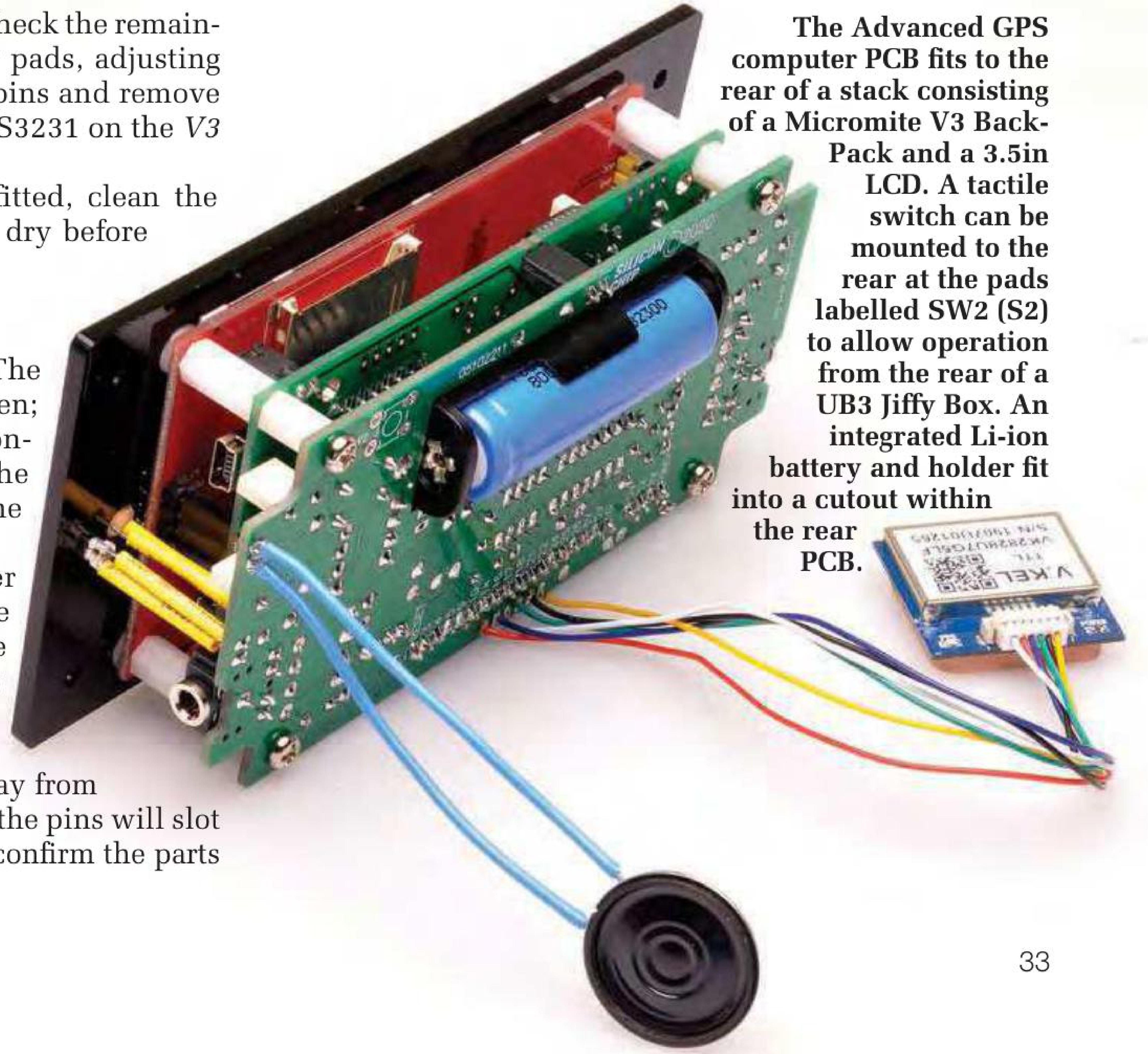
IC1 and IC2 go near the middle of the PCB, with their pin 1 markings facing away from the other. Carefully bend the leads so that the pins will slot into the PCB. Tack one lead in place and confirm the parts are flat before soldering the remainder.

Fit CON1 and CON2 next. We found that these needed to be pressed quite firmly to snap into place, but this means that you can confirm their position before soldering.

VR1 is next; ensure that its wiper goes to the topmost pin and that it sits flat against the PCB.

The 220µF electrolytic capacitor is mounted on its side, so install it next, right near VR1. Check that the negative-striped lead is closest to CON1. It's easiest to bend the leads 90° before soldering it in place.

There are six 1µF ceramic capacitors; four near IC1 and two near IC2. Their values are marked on the PCB. Follow with the two 4.7µF ceramic caps near IC4. None of these are polarised. Then mount the four 100nF MKT capacitors, then the solitary 10nF capacitor. Again, none are polarised.



The Advanced GPS computer PCB fits to the rear of a stack consisting of a Micromite V3 BackPack and a 3.5in LCD. A tactile switch can be mounted to the rear at the pads labelled SW2 (S2) to allow operation from the rear of a UB3 Jiffy Box. An integrated Li-ion battery and holder fit into a cutout within the rear PCB.

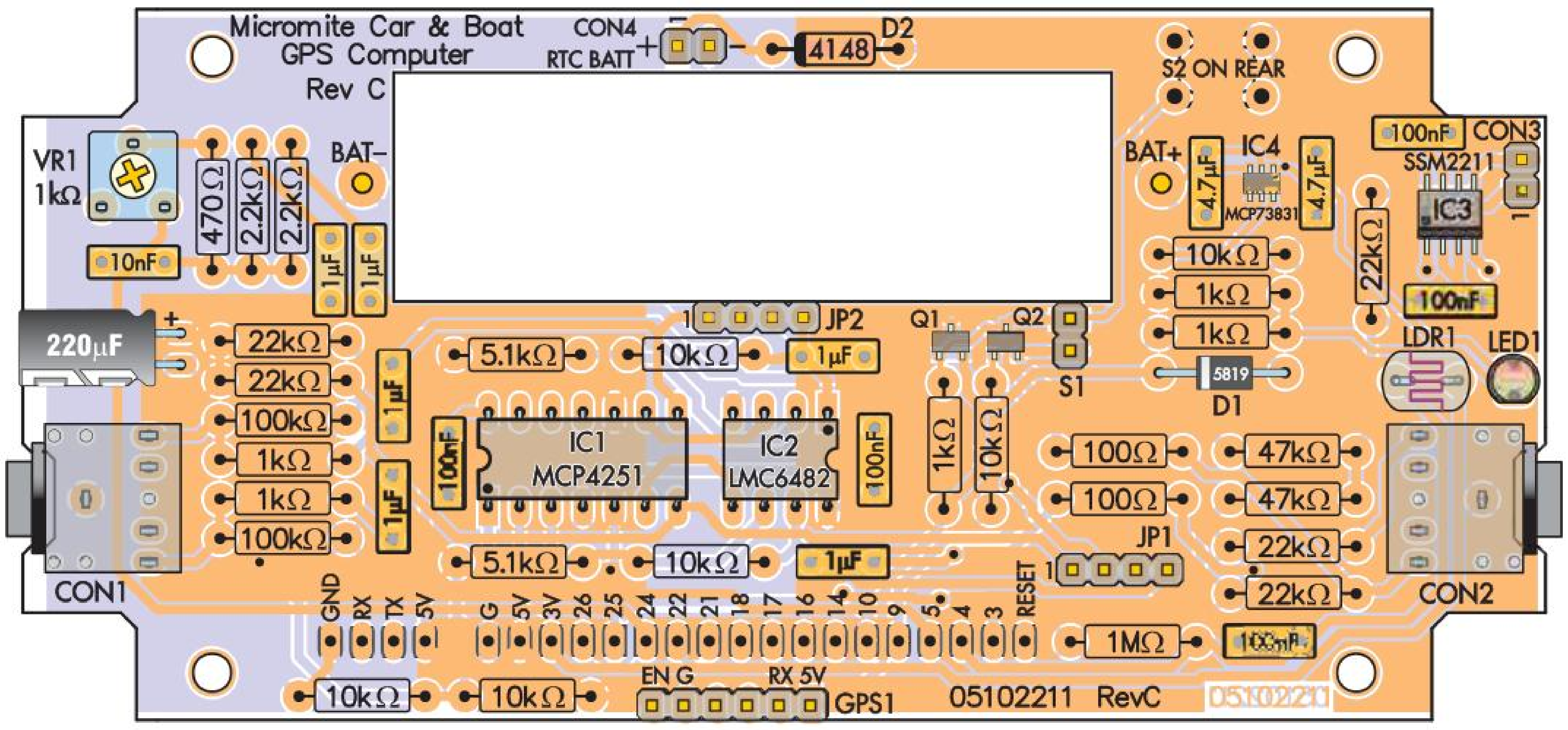

Micromite Car & Boat
GPS Computer
Rev C
CON4
RTC BATT
D2
4148
S2 ON REAR
VR1
1kΩ
BAT–
470Ω
2.2kΩ
2.2kΩ
1µF
1µF
10nF
BAT+
4.7µF
IC4
MCP73831
4.7µF
100nF
CON3
SSM2211
IC3
22kΩ
10kΩ
1kΩ
1kΩ
100nF
LDR1
LED1
220µF
22kΩ
22kΩ
100kΩ
1kΩ
1kΩ
100kΩ
1µF
1µF
100nF
5.1kΩ
10kΩ
1µF
JP2
Q1
Q2
S1
5819
D1
IC1
MCP4251
IC2
LMC6482
100nF
1kΩ
10kΩ
100Ω
100Ω
47kΩ
47kΩ
22kΩ
22kΩ
JP1
RESET
5.1kΩ
10kΩ
1µF
CON1
CON2
GND
RX
TX
5V
G
5V
3V
26
25
24
22
21
18
17
16
14
10
9
5
4
3
1MΩ
100nF
10kΩ
10kΩ
EN G
RX 5V
GPS1
05102211 RevC

Fig.2: the GPS Computer add-on board has four SMDs plus quite a few through-hole components. Of the surface-mounted devices, only IC4 has pins that are relatively close together, but there are only six of them. Ensure IC3 and IC4 are fitted with the correct orientation, then solder Q1 and Q2 and move onto the through-hole parts. The large rectangular cut-out is sized to fit a standard Li-ion rechargeable battery, either soldered directly to the board or in a holder.

We'll leave off some parts for now, including JP1, JP2, LDR1, LED1, the battery holder and tactile switch, so that we can align them correctly as part of the mechanical assembly after the headers are fitted.

Headers and mechanical assembly

Space in the UB3 Jiffy Box is tight, especially if you will be fitting the speaker and GPS module internally. Thus, we mount header sockets on the Micromite board and then solder individual male pins to the *GPS Computer* PCB, to save 2mm in height.

We've made a custom front panel for this project (rather than reusing the existing 3.5-inch BackPack laser-cut panel) for two reasons. First, it needs holes for the LDR and LED. Second, we have reverted to a design that sits 'on top' of the UB3 Jiffy Box, rather than slotting into the top cavity. This gains us another 3mm of usable space inside.

This also allows us to add another hole above VR1 to enable adjustments to be made after the unit is fully assembled.

The battery holder, LDR1 and LED1 all need to be fitted carefully to ensure they align neatly within the enclosure; that's why we've left them until now. The battery holder needs to clear both the *BackPack* PCB and the case.

There's a bit of wiggle room, but it's easier to judge when all the parts are present. As a rough guide, the battery holder's centre axis should be in line with the PCB. Similarly, the LDR and LED are fitted to be near-flush with the top of the enclosure, and this is another thing that's easier to do with everything present.

It's also easier to check and judge the holes that need to be made in the enclosure now. Everything is effectively fitted to the back of the front panel, which is then installed into the enclosure. So start with the front panel, with the matte side facing out. The LCD module fits with its 14-way header at the opposite end to the LDR and LED openings. Note from our photos how the silver connections at the touch panel's edge align with the front panel.

The LCD module is mounted using four 12mm M3 machine screws, and is stood off the front panel with M3 nylon washers, which provide space for the soldered ends of the LCD module headers. Secure the LCD module to the front panel with four 12mm tapped spacers.

If you haven't fitted the header sockets to the underside of the *Micromite V3 BackPack* already, then do this now. You can use the *GPS Computer* PCB as a jig by slotting (but not soldering) the corresponding headers in place, to align the female headers squarely with their PCB.

Now slot the *Micromite V3 BackPack* onto the LCD module, using its 14-way header. Then secure the *GPS Computer* PCB to the *BackPack* using 15mm machine screws threaded through the *GPS Computer* PCB, through the shorter spacers and *BackPack* into the previously installed tapped spacers.

Check that the pads on the *GPS Computer* PCB line up with the sockets on the *BackPack*. Then remove the pins from their plastic spacers (eg, pull them out with pliers) and slot them into the headers through these pads. There are 24 in total; one 18-way, one four-way and one two-way.

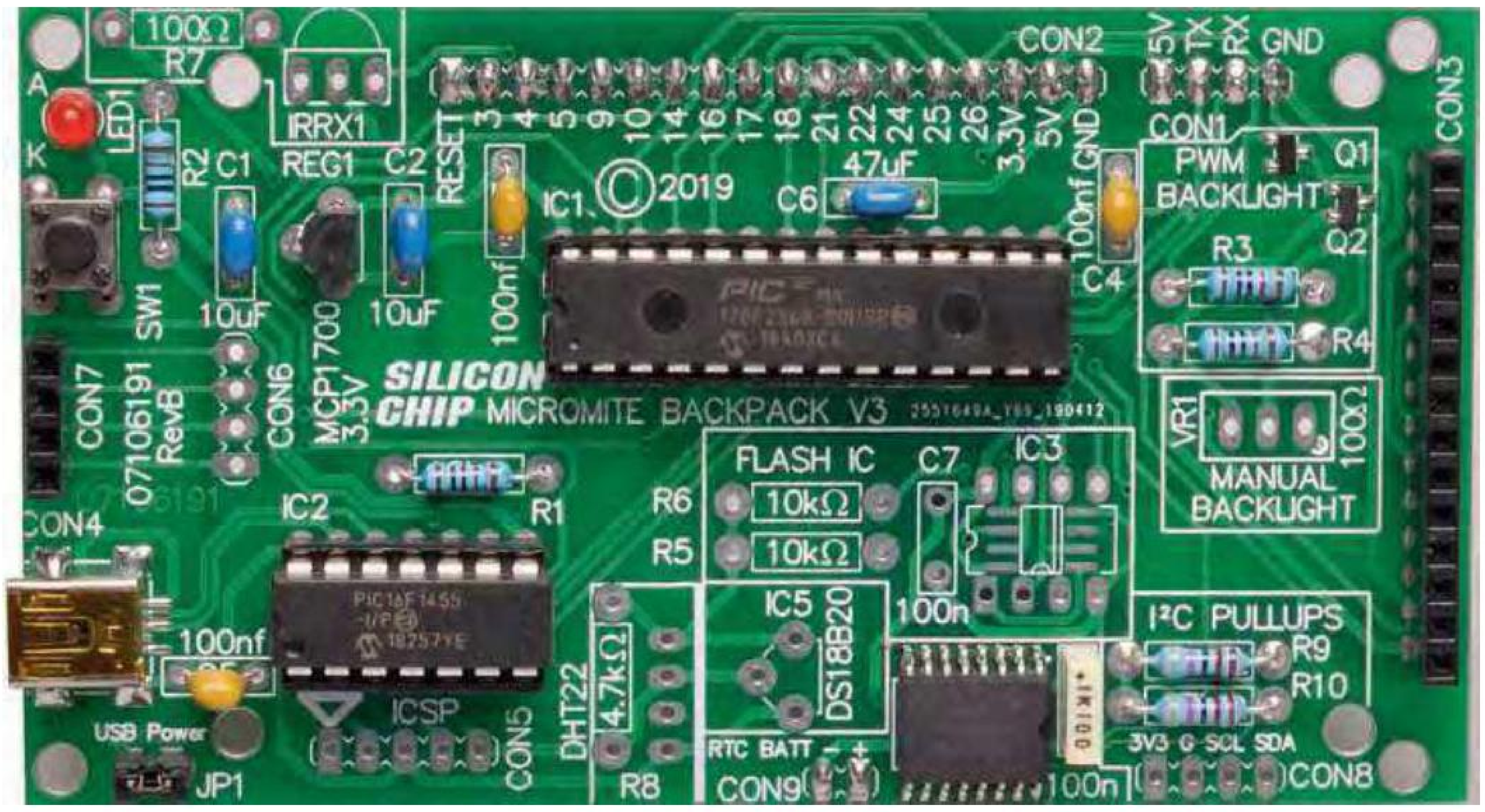
Ensure they are down firmly and level before soldering. When all are soldered, trim their ends.

Fit the LED and LDR next. Align each component with its front panel hole and the *GPS Computer* PCB pads. A piece of masking tape over the holes in the front panel is a simple way to hold the parts flush against it.

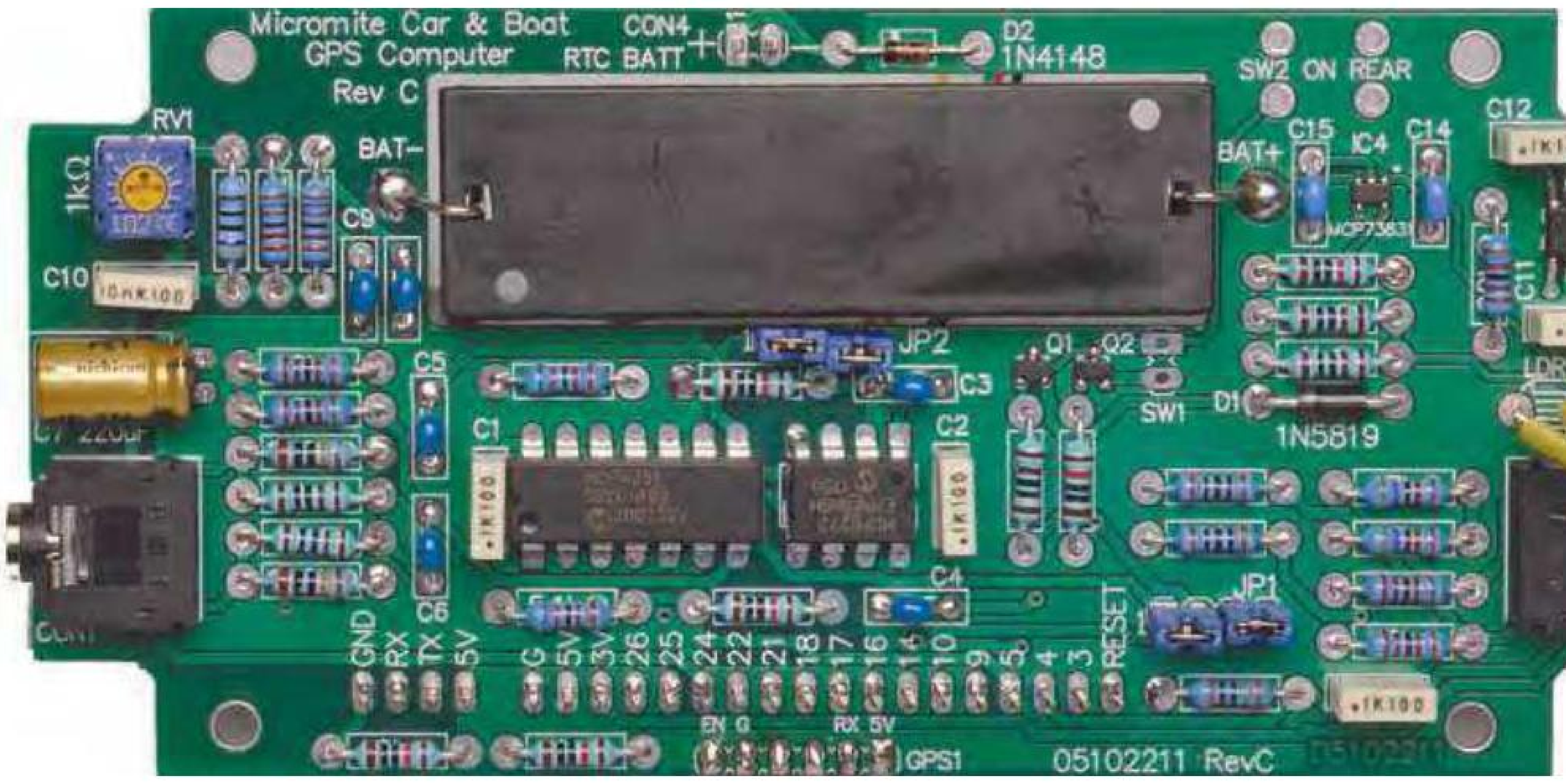
The LDR is not polarised, so can be fitted either way, but the LED orientation will matter. Set a DMM to diode test mode and connect its probes to the LED leads so that it lights up red. Failing that, use a 5V supply and a 470Ω current-limiting resistor. The lead to the red DMM probe (+) or positive supply lead is then inserted into the LED hole on the PCB nearest CON2.

Slip small-diameter heatshrink tubing over the LDR and LED leads to prevent them from contacting anything if something comes loose.

Before fitting the battery, check that the charging circuit is working correctly. Apply power to the USB socket


100Ω
R7
CON2
5V
TX
RX
GND
A
LED1
K
R2
C1
IRRX1
REG1
C2
RESET
IC1
©2019
C6
47uF
CON1
PWM
BACKLIGHT
Q1
Q2
R3
R4
SW1
10uF
10uF
100nf
100nf
C4
CON7
07106191
RevB
CON6
MCP1700
3.3V
SILICON CHIP
MICROMITE BACKPACK V3
VR1
100Ω
MANUAL
BACKLIGHT
CON4
IC2
R1
FLASH IC
C7
IC3
R6
10kΩ
R5
10kΩ
IC5
DS18B20
100n
I²C PULLUPS
R9
R10
100nf
C5
USB Power
JP1
ICSP
CON5
DHT22
4.7kΩ
R8
RTC BATT
CON9
100n
3V3 G SCL SDA
CON8
CON3

The V3 BackPack should look like this when fitted with the DS3231 RTC IC and its associated passives. The 5V USB power jumper is required too, as seen in the lower left corner. Also note the two-pin header (CON9) soldered to the underside of the BackPack PCB.



When constructing the PCB, note that the Micromite and GPS headers are individual pins that are installed without their plastic shrouds by fitting them into their matching headers before soldering. The LED and LDR (shown with yellow heatshrink on their leads) are installed last to ensure they align with the front panel; SW2 with the back panel.

on the *BackPack* PCB; the voltage at the battery terminals should settle around 4.3V. The LED should also briefly light up green (perhaps after showing red), indicating that the charge IC has reached its 'full' voltage. If it is showing red, try reversing the LED.

If it is near 5V, then there might be a fault which is connecting USB power directly to the battery. Do not connect the battery if this is the case! Fix the problem before proceeding, as such a fault could damage the battery or cause a fire. Disconnect USB power and unplug the *GPS Computer* PCB.

Connecting the battery

If you have a battery with tabs, you should take great care not to bridge any parts to the battery except the terminal you are working on. Beware that your iron may be earthed and there may be a path for current through it if it touches anything else. And of course, double-check the polarity!

Fitting a holder is preferred, as we don't have to worry about working with the live battery, and can pop it out before working on anything. It will also be much easier to change in future should it fail.

Note from our photos that the battery faces outwards, allowing it to be changed if needed. In the unlikely event of it falling out, it will be held against the plastic enclosure rather than being thrust against the sharp edges of the *BackPack* PCB.

Bend the leads so that the battery holder can be fitted to the PCB, then slot the leads into their pads. Then reattach the *GPS Computer* PCB to the *BackPack* to check locations and clearance. You might even like to use a plastic spacer to provide positive separation.

Check the polarity, then use a generous amount of solder to secure the battery holder. When finished, remove the *GPS Computer* PCB.

You can now fit JP1 and JP2, using a similar technique to the other headers, removing the pins from the plastic housing to reduce their height. If you have a spare four-way header socket, this can be used to secure and align the pins as they are soldered.

Alternatively, if you intend to have a permanent setting for JP1 and JP2, these can be replaced with small wire loops soldered directly to the PCB pads.

Press the PCBs together to check that JP1 and JP2 do not foul the *BackPack* PCB. Then fit the battery and reattach the PCB to the stack. Now is a good time to trim the short lead stubs at the back of the *GPS Computer* PCB.

Installing the GPS module

As we noted last month, we found that the POWER LED on the VK2828 GPS module drew about 2mA, even with the ENABLE pin taken low. Removing the LED brought this down to 40µA, so we suggest you do the same before fitting it.

Next, solder the GPS module and speaker to their terminals. Note there are only four connections needed. Since the VK2828 modules have two spare leads, these can be terminated to either of the spare pads on GPS1 to stop them from floating around.

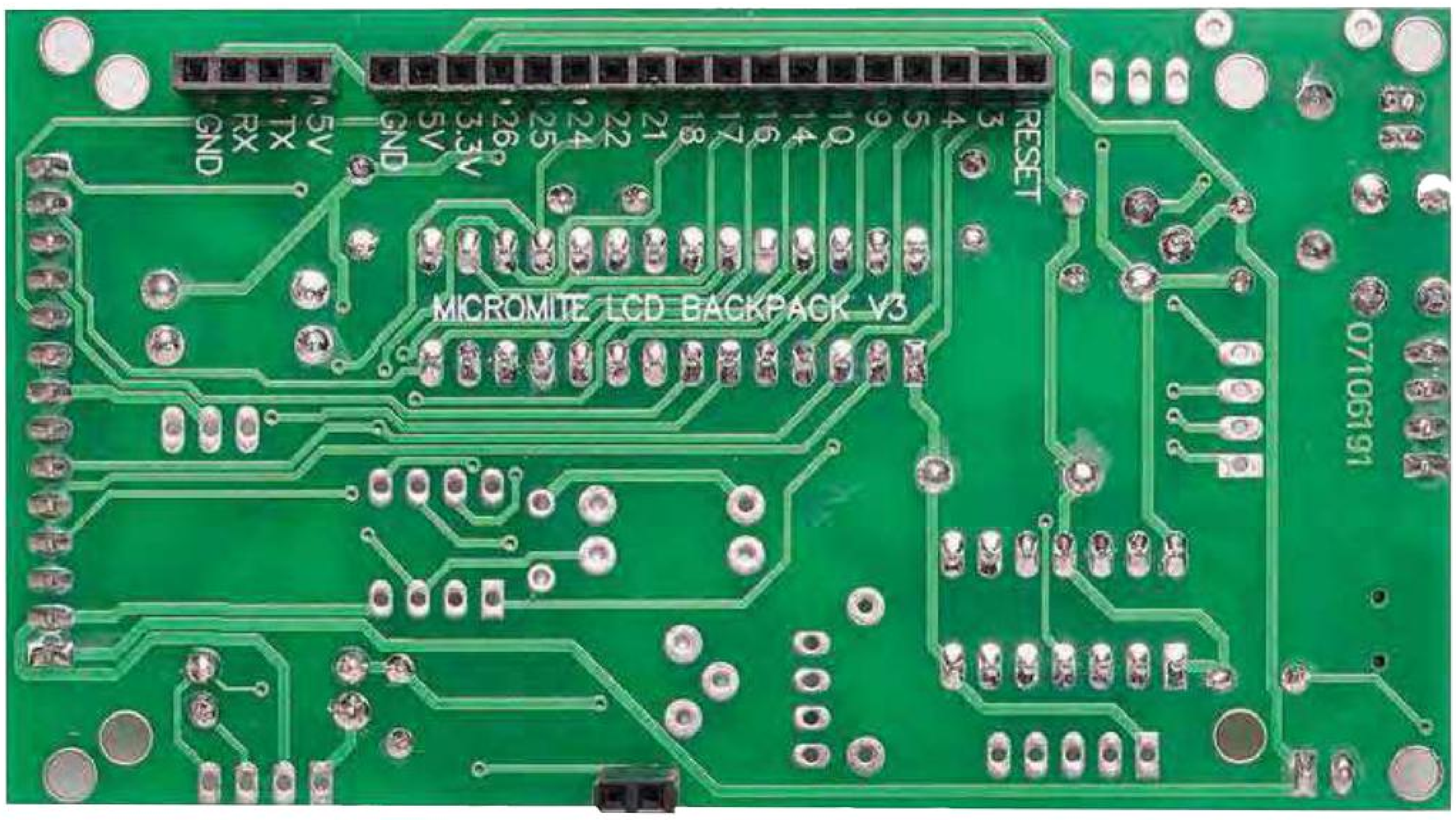
We attached the GPS module and speaker to the PCB's rear using double-sided tape during testing. Once everything is working, they can be secured with neutral-cure silicone sealant. We wouldn't use hot-melt glue as it could loosen if the unit is inside a hot vehicle parked out in the sun.

The assembly should slot into the UB3 case comfortably. If not, check your clearances before proceeding.

Case cutting

There are four holes to cut in the case – refer to the cutting diagram, Fig.3. It's a good idea to check this against your assembled board, to ensure that everything is aligned and any minor variations in construction are accounted for.

The 3.5mm sockets are set behind the panels to prevent the PCBs from catching on the case. Thus, you might need to enlarge these holes if you have bulky 3.5mm leads. This is easily done with a larger or stepped drill bit, or a tapered reamer.



We have fitted the V3 BackPack with female headers (like the RCL Substitution Box from June and July 2021). This allows shortened male headers to be installed on the GPS Computer PCB, making the final assembly more compact, to better fit into the box.

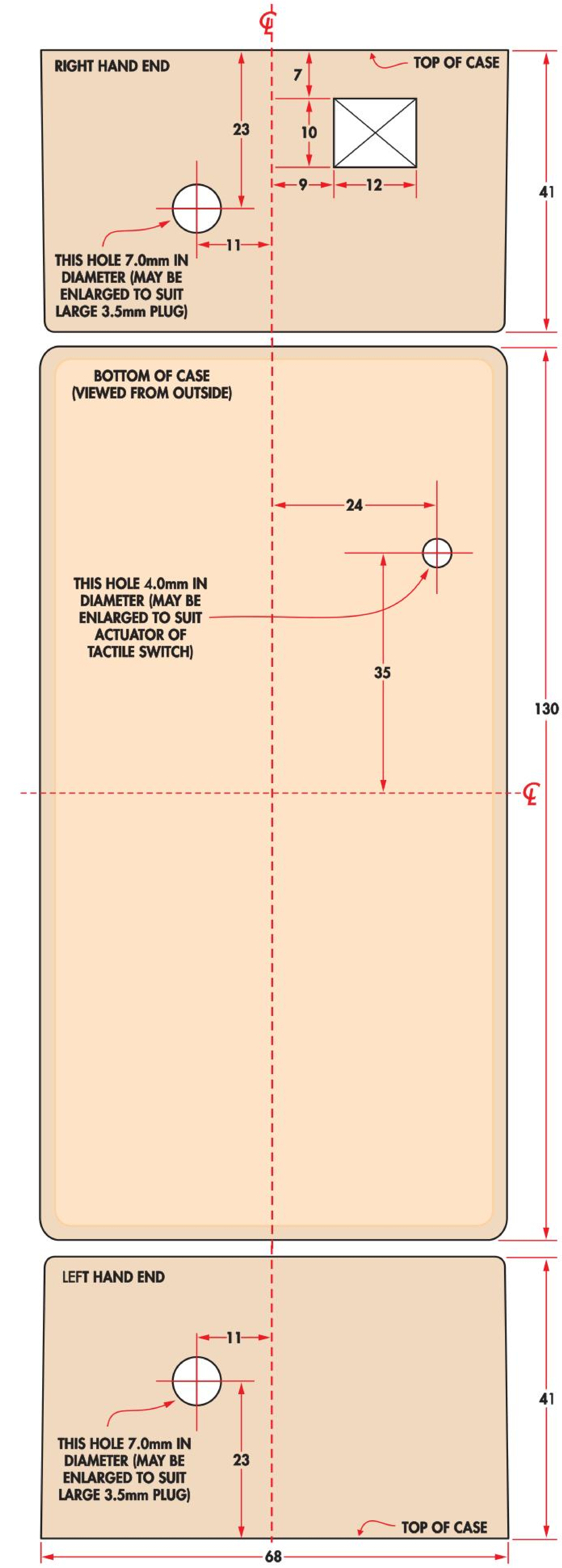

RIGHT HAND END
TOP OF CASE
7
23
10
9
12
41
11
THIS HOLE 7.0mm IN DIAMETER (MAY BE ENLARGED TO SUIT LARGE 3.5mm PLUG)
BOTTOM OF CASE (VIEWED FROM OUTSIDE)
24
THIS HOLE 4.0mm IN DIAMETER (MAY BE ENLARGED TO SUIT ACTUATOR OF TACTILE SWITCH)
35
130
LEFT HAND END
11
41
THIS HOLE 7.0mm IN DIAMETER (MAY BE ENLARGED TO SUIT LARGE 3.5mm PLUG)
23
TOP OF CASE
68

Fig.3: there are just three holes in the sides of the box (two round holes for the 3.5mm jack sockets and a rectangular one for USB) plus a 4mm hole in the rear of the case to access the tactile power-on switch. Or you can fit a chassis-mounting switch instead.

To create the square hole for the USB lead, we suggest drilling a 10mm hole within the outline. Then open out the corners with a needle file or similar. You can use a pencil to draw guidelines on the enclosure before cutting. A simple wipe with a finger is enough to remove pencil marks.

The diagram also shows the location for a hole if you have a PCB-mounted tactile switch fitted to the S2 pads. A button with its actuator top 12mm above the PCB will sit just behind the panel (requiring a pen or similar to operate), while one that is around 15mm will sit just proud of the enclosure and be more accessible.

So you should choose a height that suits how accessible you want the switch to be. Alternatively, any momentary switch can be run back to the terminals marked S1. This will allow you to fit a panel-mount pushbutton to the side or top of the case if the back is not suitable.

We haven't included any speaker vent holes; these will depend on your speaker's size and location.

Programming the chips

There are a few ways to program the microcontrollers for this project. You can use the in-circuit serial programming (ICSP) interface to upload a HEX file (using either the Microbridge or an external programmer such as a PICkit 4), but remember to detach the *GPS Computer* PCB so that its connections do not cause a conflict.

Use your programmer's instructions to upload the HEX file (GPS COMPUTER V30 (0510221A).hex), which you can find on the July 2022 page of the *PE* website.

If you have a *V3 BackPack* that is already running MMBasic, you don't need to worry about ICSP programming.

We usually use MMEdit to work with BASIC files, but the process is much the same if you use TeraTerm instead.

We've used MMBasic version 5.5.3, and we recommend you do the same, especially if you are installing MMBasic from scratch. We have not tested our code with other versions.

Load the **GPS Computer Library.bas** file into the Micromite. Then, via the terminal, run the commands:

```
LIBRARY SAVE
CPU RESTART
```

The Micromite will reset and load the ILI9488 display driver. Now you can run:

```
OPTION TOUCH 7, 15
GUI CALIBRATE
```

These commands are noted in the comments at the start of the library file. You can test the touch and LCD with these commands:

```
GUI TEST LCDPANEL
GUI TEST TOUCH
```

Next, load the main **GPS COMPUTER V30.bas** file and run it. If you have trouble with the **GPS COMPUTER V30.bas** file, try the crunched version (with a 'c' suffix: **GPS COMPUTER V30C.bas**). This has had all the extraneous whitespace and comments removed.

We found that our program was so large that even the 'crunch on load' option does not remove enough whitespace; it appears to leave some behind to maintain line numbering.

This will get the Micromite to the same state as if it were programmed with an ICSP programmer and HEX file.

Setup and basic use

Reassemble the stack if it is not complete, and supply power via the USB socket. A splash screen will appear for a few seconds, after which the MAIN MENU page (Screen1) should be displayed. If not, you might need to run the MMBasic program from the prompt, using a serial terminal program at 38,400 baud.

Code in depth

Since we have had so many requests for tweaks and updates to the Boat Computer, we will provide a bit more background on the inner workings. We are pretty much at the limits of what MMBasic can store in the Micromite's Flash memory, so some things have been done in terse and non-obvious ways to save Flash memory.

The following is detailed. It isn't critical to understand it; you certainly won't need it to operate the GPS Computer with its default programming, but rather if you're interested in making code changes.

As with many Micromite projects, the colour scheme is set by several CONST values near the start of the program. Altering these is one of the simplest ways to personalise the GPS Computer.

The chime sound heard alongside messages is defined just after the splash screen is displayed and is held in the BELL variable. Although declared as an integer type to allocate memory, it is processed as an array of bytes. It is created by a formula which generates a decaying sinewave which goes for 8000 samples, or one second.

Changing this formula is the easiest way to customise this sound. The click sound (when buttons are pressed) and voice warning are stored in Flash memory as part of the library file.

The tile feature works through the TILE function, which calls individual functions based on each tile type. These specific functions can draw the tile graphics (using the coordinates they are set to), report their width or height (so the COMPOSE page can display them), or react to a button press.

Creating new tiles will require other tiles to be replaced. The tile name is stored in the T_TYPE string array. Many tiles depend on other functions that return strings representing numerical values adjusted for and suffixed with the currently selected units.

Any time the Micromite is not busy, it calls the IDLE subroutine, which attends to background tasks such as receiving and processing GPS data. It behaves like MMBasic's PAUSE, but does other activities and can return control to the main program if a touch is detected on the touch panel. It also periodically updates the top right of the display, and adjusts the volume and backlight as needed.

The number of pages, tiles and POIs are limited by the amount of available VAR SAVE Flash memory; for the Micromite, this is 2kB. If you wish to adjust the balance of these items, the PG_CNT, ITEM_COUNT and POI_COUNT constants can be changed. We have already pushed these number to their limits, so increasing any one will require another to be decreased.

Note that the MAIN MENU page only has room for up to six pages, so any more than this will not be accessible through the existing interface.

Library and CFUNCTIONs

The ILI9488 display driver is not new, and is based on code by Peter Mather at the Back Shed Forum (an excellent resource for Micromite-related discussion). See: **www.thebackshed.com/forum/ViewTopic.php?TID=11419**

Apart from the GPS and audio CFUNCTION, we've also incorporated some CFUNCTIONs as wrappers for data to be stored in Flash. These aren't actual executable code, but can be stored compactly without the overhead of MMBasic.

The COMBINED CFUNCTION incorporates the audio and GPS features that we use in this project. Each sub-function is invoked by calling the COMBINED function with a different first parameter. These parameters are listed near the start of the MMBasic code as the API (application programming interface) numbers paired with named constants.

For example, function 0 (CONST AUDIO_INIT) starts the timer interrupt in preparation for other functions. If you are using the LPC samples, then the CFUNCTION needs to know the location for some constant parameters. These can be set by pointing them to one of the data CFUNCTIONs noted earlier using API function 11, thus:

```
JUNK=COMBINED(LPC_SET_CONST_PTR,
  PEEK(CFUNADDR LPC_CONST))
```

With this done, we can play audio samples. API function 4 (AUDIO_GET_STATE) reports the current state to avoid interrupting playback in progress. API function 1 (AUDIO_SET_PTR) sets the PCM data pointer, while API function 2 (AUDIO_PLAY) starts playback, like this:

```
IF COMBINED(AUDIO_GET_STATE)=0 THEN
  JUNK=COMBINED(AUDIO_SET_PTR,
    PEEK(CFUNADDR CLICK))
  JUNK=COMBINED(AUDIO_PLAY)
ENDIF
```

Replacing API function 2 with API function 6 (AUDIO_LOOP) will cause the sample to loop, while API function 7 (AUDIO_END_LOOP) will cause a looping sample to revert to non-looped playback. This means that it will complete the current cycle instead of being cut off abruptly.

We've written a small program in C which can convert WAV files into MMBasic CFUNCTION data; this is in the software collection as sample.c, compiled for Windows as sample.exe.

Playback of LPC data works similarly, using API functions 8 (AUDIO_LPC_PTR) and 9 (AUDIO_LPC_START) respectively. We've included a spreadsheet document which can translate Arduino LPC sample definitions into CFUNCTION data.

GPS decoding works similarly. API number 48 (GPS_SET) sets a pointer to a string variable which is filled with data from the GPS module by the MMBasic code. The MMBasic string variable format consists of one byte indicating the length, followed by up to 255 data bytes containing the string contents, eg:

```
JUNK=COMBINED(GPS_SET,
  PEEK(VARADDR GPS_DATA))
```

API numbers 50-55 (GPS_PARSER0 – GPS_PARSER5) set pointers to string arrays. The first element of each array is filled with the sentence signature that is scanned for:

```
GPRMC_PARSE(0)="$GPRMC"
```

When API number 49 (GPS_PARSE) is executed and finds a valid sentence, it reports the matching parser's API number and copies the sentence elements (which are simply separated by commas) into the remaining array elements. Since certain items are always found at certain sentence locations, the appropriate array elements always contain the necessary data.

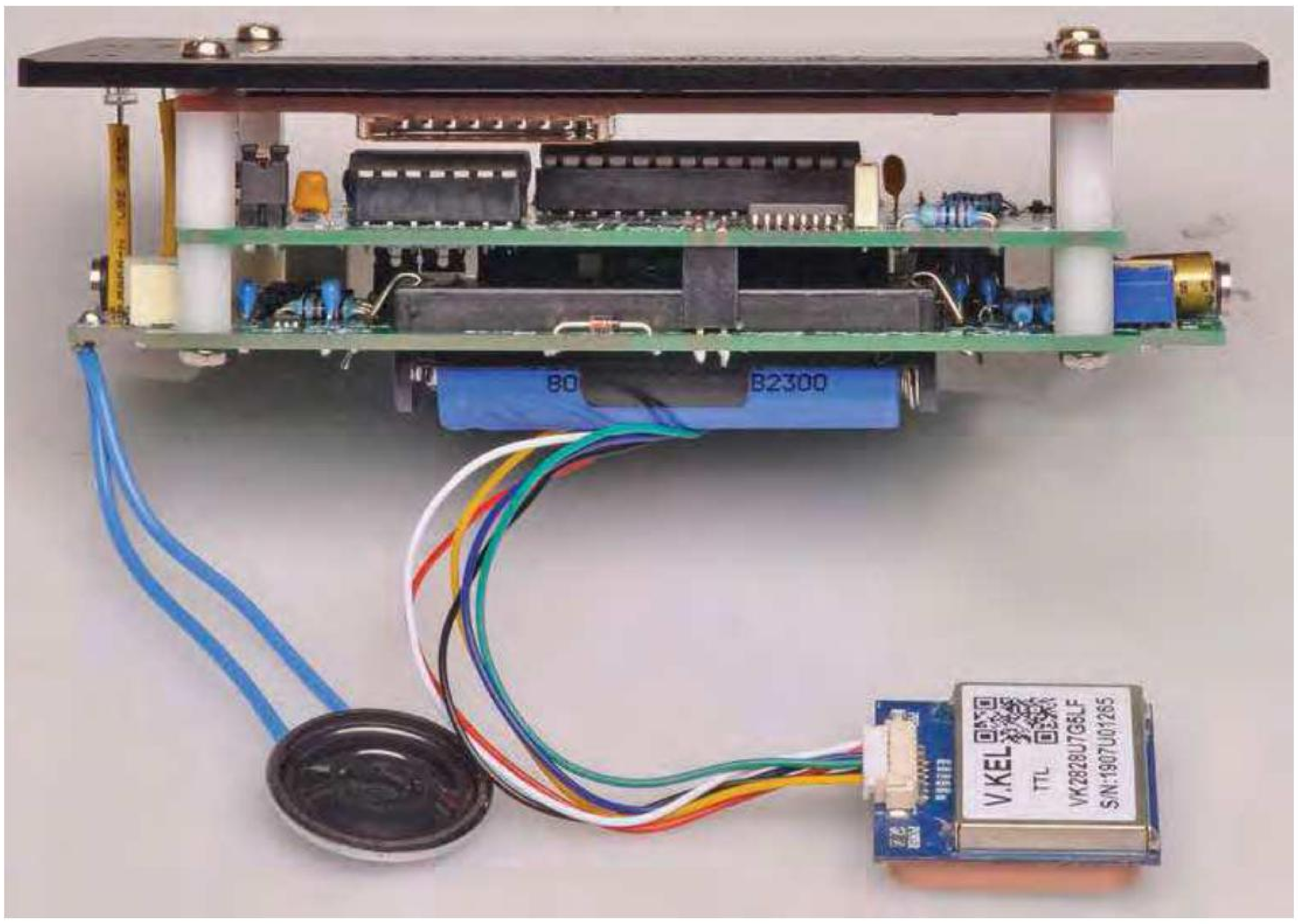
Note that the string array dimensions and lengths are hard-coded into the CFUNCTION and must match.

Once the elements are copied, the array elements containing latitude and longitude can be decoded into degrees, minutes and fractional minutes by using API numbers 61, 62 and 63, respectively. These return integers as there is much more overhead required for CFUNCTIONs to work with floating-point numbers.

While the splash screen is displayed, the Micromite is busy generating audio data for later playback. It requires less Flash memory to generate these into RAM than to hard-code them, so we put up with the brief delay while this happens.

Since the Flash memory is quite full, but barely half the RAM is used, this is to our advantage.

All screens will display the information seen at top right. You can quickly check the time, GPS status (a red or green G) and battery state at a glance.



Here's a side view to show how tightly everything is packed into the stack of PCBs, allowing room for a GPS module and speaker inside the UB3 Jiffy Box.

The time can be set to 12-hour or 24-hour format; the 24-hour format shows seconds as it does not need room to show the AM/PM indicator.

At first start, the red 'G' will be displayed until the GPS receiver is outputting valid data, which could take 15 minutes for the first time, even under good conditions. The battery icon should show a green charging symbol when connected to USB power.

Pressing any button will trigger a short click to let you know that the button press has been detected, while a short chime accompanies messages and errors. The volume of these can be adjusted using VR1.

The RAW DATA page (Screen2) helps with checking the GPS state. Check the satellite count; if you don't see at least four after 15 minutes, and you have good sky visibility sky, there might be a problem with the GPS module. Zero satellites may mean that the GPS module is not receiving signals at all.

The EXIT button will always return to the MAIN MENU. The SETTINGS page sets most user preferences such as units and *GPS Computer* behaviour.

The five top items down the left-hand side (Screen3) are the settings for display units; pressing each button cycles between three and six options.

These include three styles for latitude and longitude, including degrees, minutes and seconds, decimal degrees and the decimal minutes mode which GPS modules use. The latitude and longitude sign can be displayed as N/S or E/W, negative sign only (with implied positive sign) or explicit positive and negative signs.

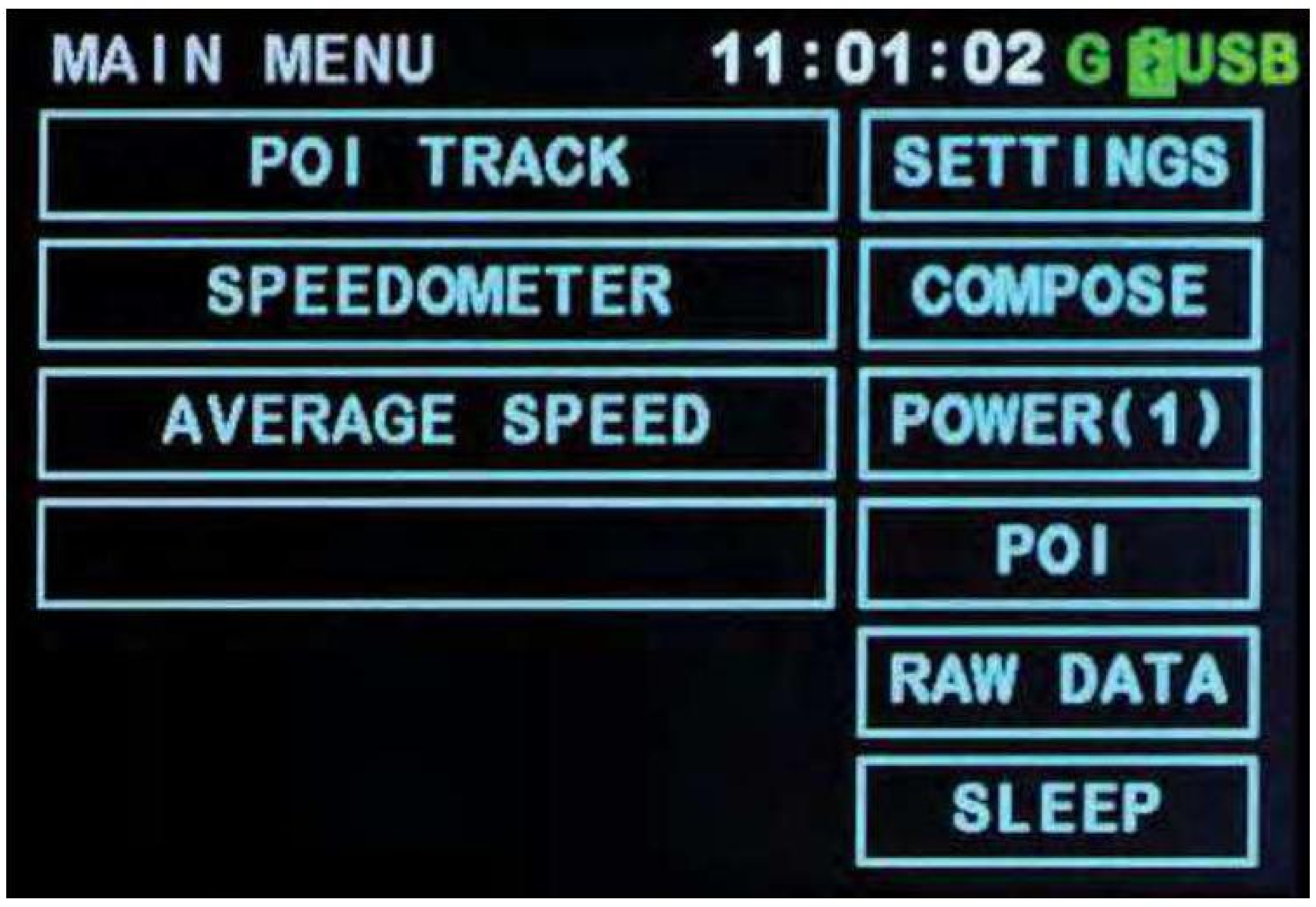
Both horizontal distance and vertical distance units can be set independently. The choices are metres, feet, kilometres, miles, nautical miles or flight level. Flight level is measured as multiples of 100ft and is often used for altitude in aviation.

Speed offers the choice of metres per second (m/s), kilometres per hour (km/h), miles per hour (mph) or knots (equal to nautical miles [NM] per hour). None of these options are stored permanently until the SAVE button is pressed. This reduces wear on Flash memory, and allows you to test settings before committing to them.

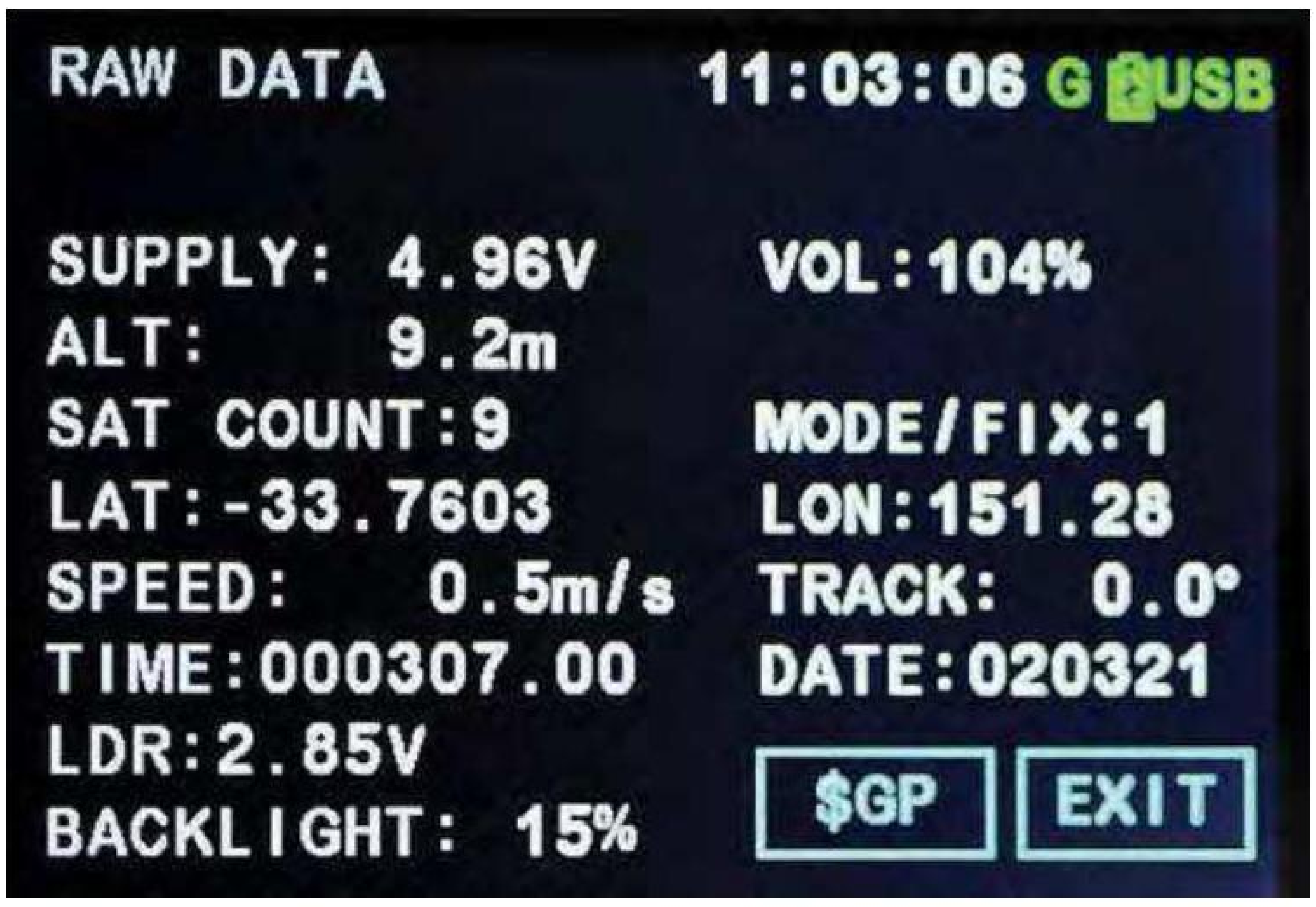
The bottom item at left is for adjusting some numerical values. The ← button cycles between time zone, backlight high, backlight low, speed high, speed low, volume high and volume low. You can adjust each value with the + and – buttons.

A short press increments or decrements each value by a small amount, while holding the button down allows it to change quickly. The time zone changes by 15-minute increments.

The backlight high and low settings set the brightness in high and low light conditions, respectively; the *GPS Computer* interpolates between these. Set the high level to be comfortable in daylight, and the low level to be comfortable at night (or when the sensor is covered).



Screen1: on power-up, and whenever the EXIT button is pressed, the GPS Computer displays the MAIN MENU screen. Four custom pages are accessible through the buttons at left, while the buttons at right provide options to change settings and customise pages.


RAW DATA 11:03:06 G USB

SUPPLY: 4.96V VOL:104%
ALT: 9.2m
SAT COUNT:9 MODE/FIX:1
LAT:-33.7603 LON:151.28
SPEED: 0.5m/s TRACK: 0.0°
TIME:000307.00 DATE:020321
LDR:2.85V
BACKLIGHT: 15%

Screen2: this page allows some troubleshooting of the GPS Computer. The satellite count is a good indicator of any problems the GPS module might have; we typically saw 11-12 satellites using a VK2828 GPS module.

Speed-based volume control

Similarly, the high-speed setting corresponds to the speed at which the high volume setting is used, and the low-speed setting to low volume. Note that the displayed units will match the currently selected units. Internally, all speeds are in m/s and converted as needed.

See Fig.4 for a graphical explanation of this. We suggest leaving the low and high speeds around these values, then getting a passenger to adjust the volume levels to be comfortable when travelling around the low and high speeds.

This is because there won't be much road or engine noise below 30km/h, and not much change above 80km/h. If you find this isn't the case, then you can try tweaking these values too.

Remember that both brightness and volume are programmed to ramp quite slowly (around 10% per second), so give the unit time to respond to significant changes.

The RTC always keeps track of coordinated universal time (UTC), and the local time to display is calculated from that, based on current time zone and daylight savings settings. Turning daylight saving mode on and off is done by pressing the DST button.

A '+' indicates that daylight savings is in effect and one hour is added to the current offset; a '–' means no adjustment from the set time zone.

In practice, if you live somwhere which uses DST, you should only need to adjust the time twice a year by merely pressing the DST button to turn daylight savings on or off.

When the *GPS Computer* displays a green 'G' icon, pressing the TIME button will save the current GPS time to the RTC. If you get an error message, it might be that the RTC IC is not connected or not working correctly.

The 12HR or 24HR button toggles how the time is displayed; the style shown on the button is currently active. The button marked 'S<' or 'S–' indicates whether the synthesised audio output is activated; again, the button shows the current state.

Battery sensing

The six buttons at top right of the SETTINGS page control battery behaviour. The HI voltage is the threshold below which it is assumed that USB power is not available, while the LO voltage sets the lower limit for battery operation, below which the unit will shut down.

In use, the battery icon will be green above HI and yellow between HI and LO. A bar-graph showing rough state-of-charge and a percentage are shown in the yellow phase.

Below LO, the TO timer starts counting, and this is shown in red next to a red battery icon. When the timer expires, the software takes pin 9 low, meaning that the unit will power off if running from battery power. Any time the voltage rises above LO, the timer will reset.

The defaults of 3.8V for LO and 4.4V for HI mean that the *GPS Computer* should run for as long as practicable from a Li-ion battery. The MAIN MENU page also shows the state of pin 9 as POWER(1) or POWER(0). Pressing the button will toggle the pin state.

You can use this to force the *GPS Computer* to shut down even if it has some remaining battery life.

The MAIN PAGE also has a SLEEP button, which turns off the backlight and puts the Micromite into its lowest power mode. The GPS module is still fully powered, so should be able to maintain a satellite fix. This is handy for conditions where you wish to save power but also require the *GPS Computer* to start up again with minimum delay.

Pressing the screen for around one second will cause the *GPS Computer* to leave sleep mode. The long press is needed as the Micromite can only test for touches once per second in its low-power sleep mode.

Points of Interest (POIs)

The POI EDITOR feature (Screen4) is accessed from the POI button on the MAIN PAGE. Five POIs are displayed

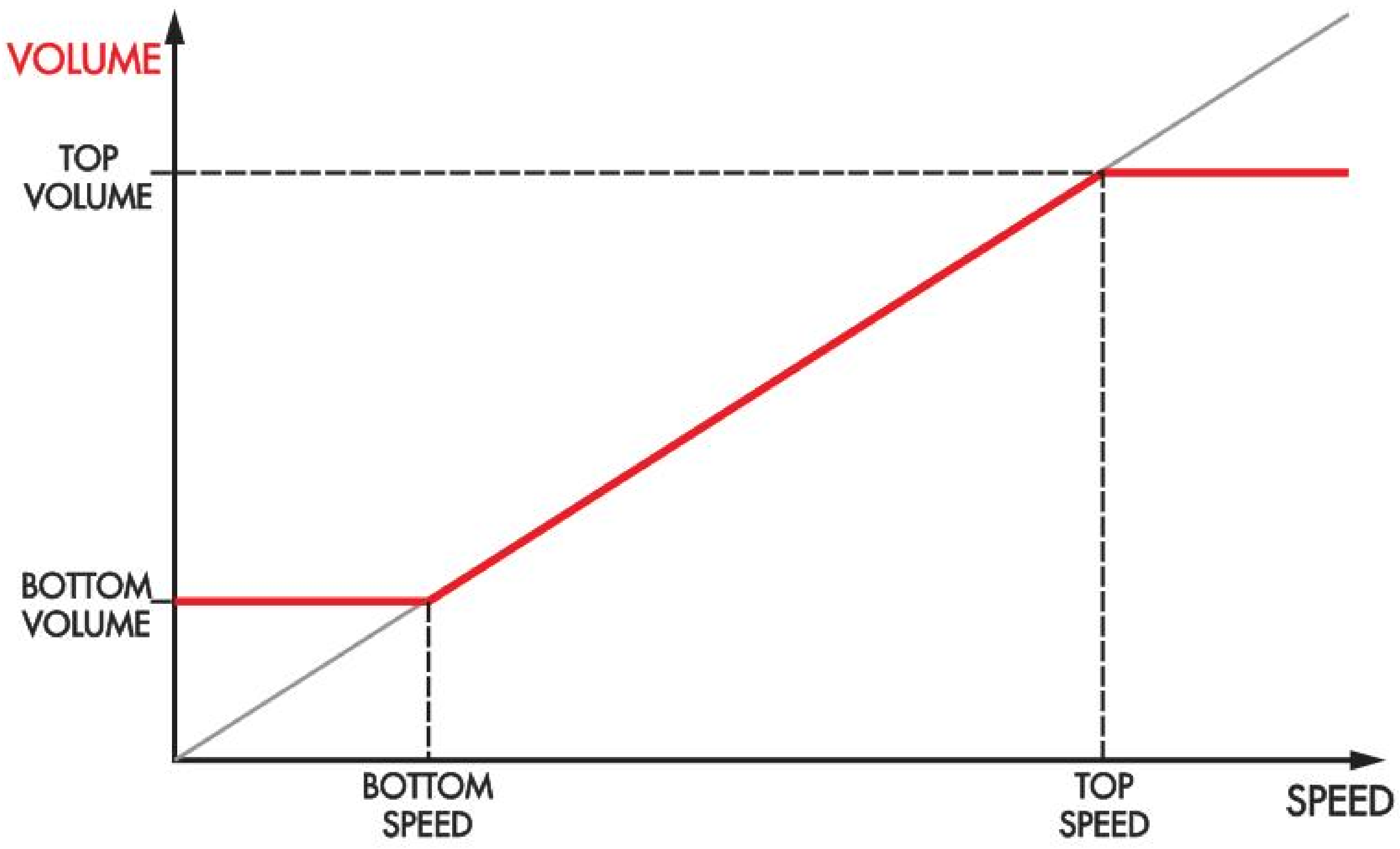
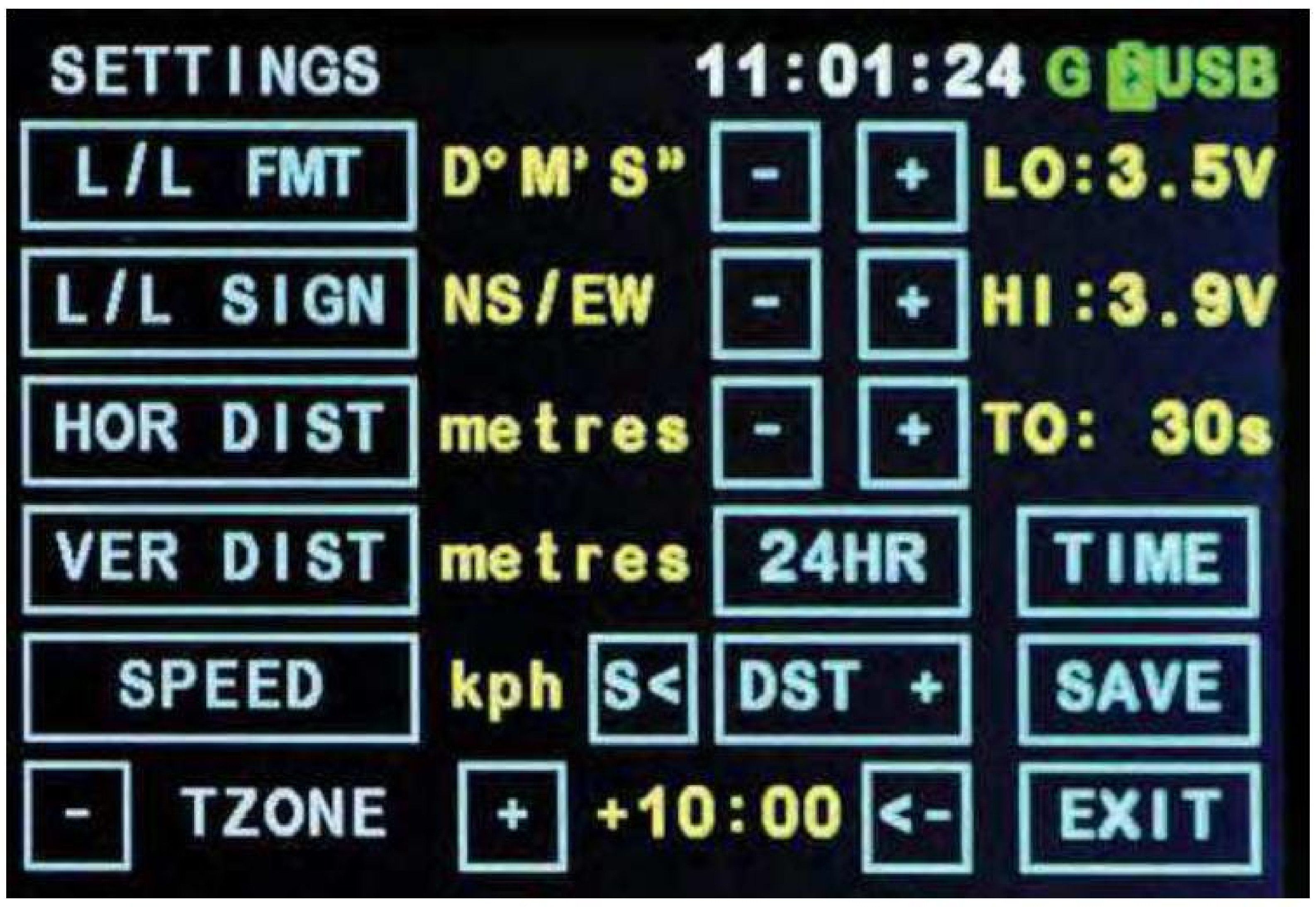
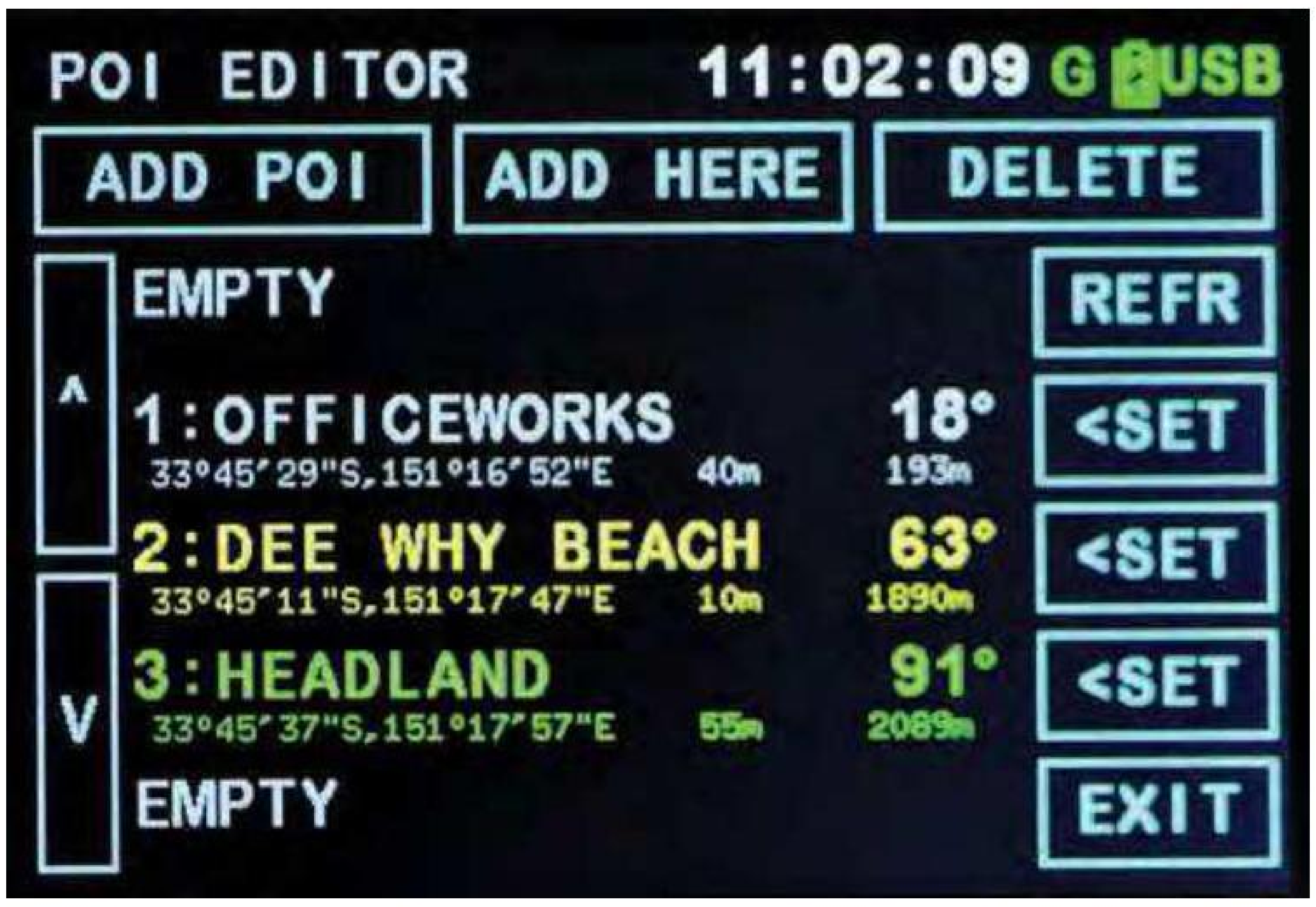


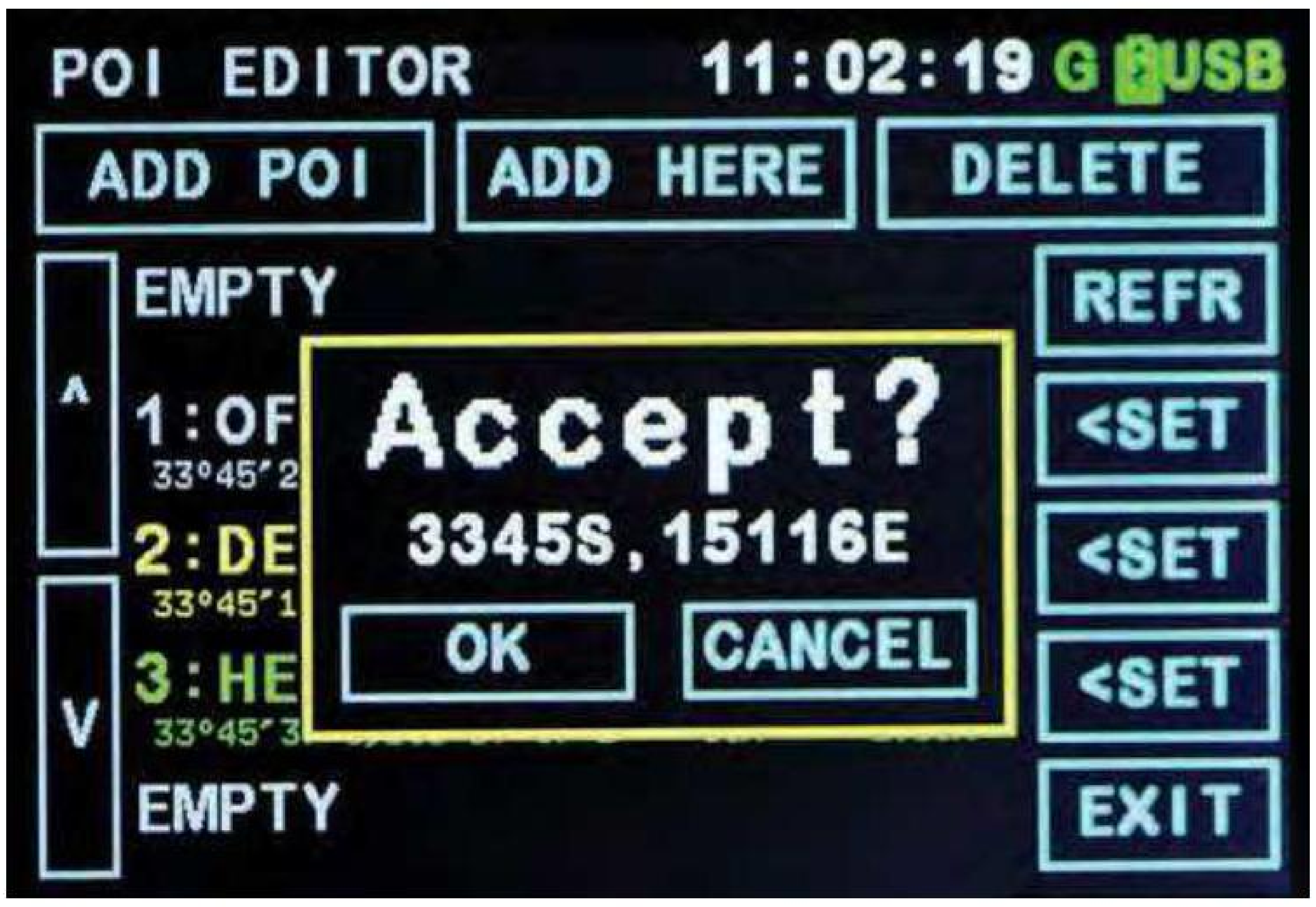
Fig.4: if you are using the speed-sensitive volume control feature, this is how it works. The volume is fixed from stationary up to the low-speed threshold, after which it rises until reaching the maximum volume setting at the high-speed threshold.



Screen3: we have crammed a lot onto this screen to cater to most users' preferences. The SAVE button is needed to save any parameters to Flash memory (to be saved through power-down), including POIs (points of interest) and custom page layouts.



Screen4: the POI (point of interest) EDITOR allows the current coordinates to be quickly saved with the ADD HERE button. Any POI can be activated by scrolling up or down and then pressing the SET button at right.


POI EDITOR
11:02:19
G
USB
ADD POI
ADD HERE
DELETE
EMPTY
REFR
^
1:OF
33°45'2
<SET
2:DE
33°45'1
<SET
3:HE
33°45'3
<SET
V
EMPTY
EXIT
OK
CANCEL

Accept?
3345S,15116E

Screen5: the ADD HERE button provides a default name based on the coordinates; You can alter it by pressing the cancel button and using the keyboard. You will be prompted to confirm the name before it is stored.

from a larger list, and the complete list can be accessed by pressing the scroll buttons at left. One POI is marked in green; this is the currently active POI and is activated by one of the SET buttons at right.

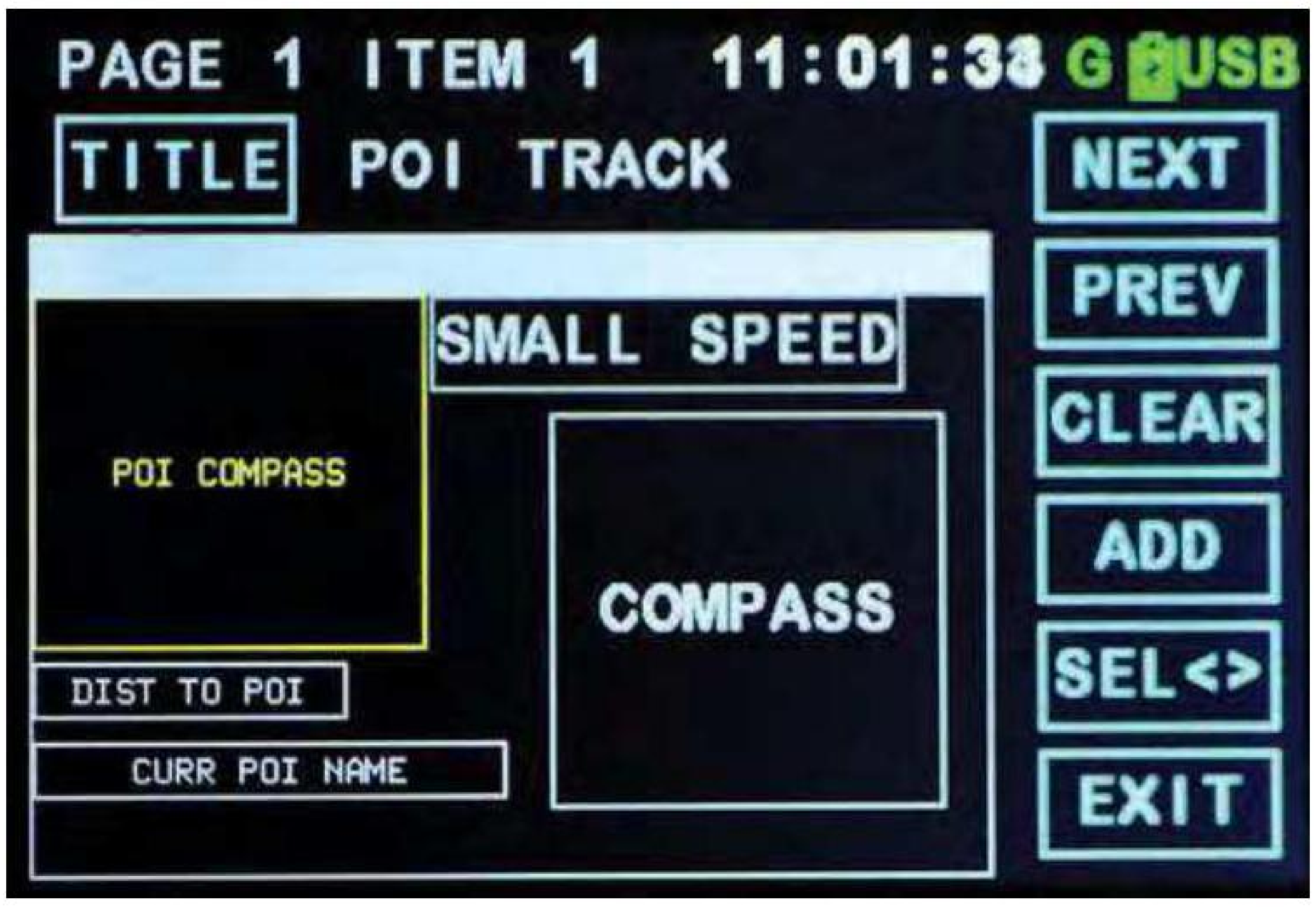
The current POI is used in any of the screens that provide POI tracking. Each non-empty entry shows a custom name, an absolute compass heading toward the POI, as well as its latitude, longitude, altitude and distance away.

Pressing the ADD HERE button creates a POI with the current GPS coordinates; a default name based on the latitude and longitude is offered, but can be altered by pressing CANCEL.

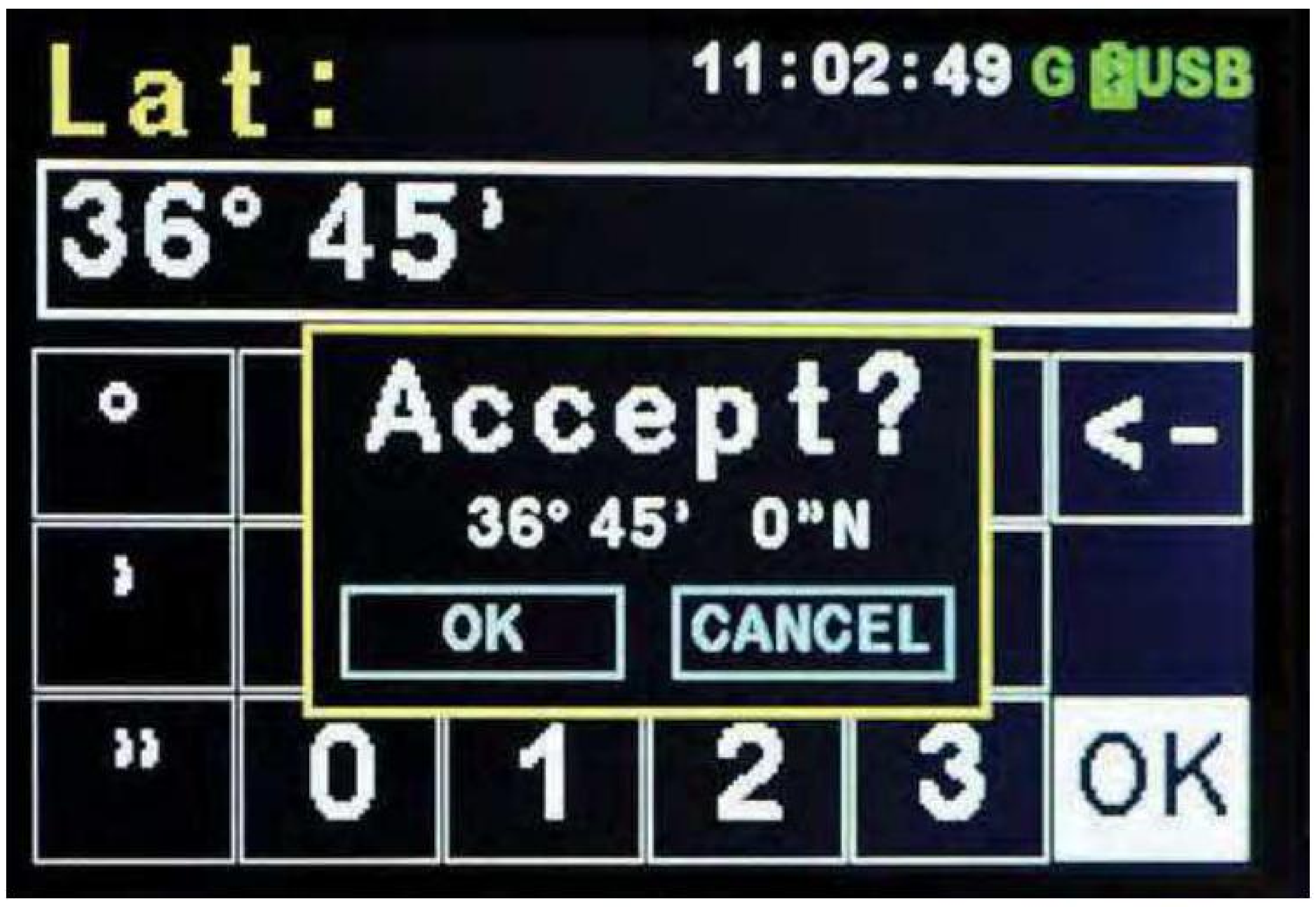
The ADD POI button allows all this data to be entered manually, such as creating POIs from a map or GPS coordinates. Screen5 and Screen6 show the relevant entry displays. Latitude and longitude can be entered in either decimal or degrees/minutes/seconds format; the value is converted to the currently set units for confirmation.

Both ADD buttons will always look for an empty slot, so there is little risk of overwriting an existing POI. The DELETE button needs to be used to clear a slot, and an error message is provided if there are none.

Finally, the REFR button refreshes the display. This is necessary as the headings and distances do not automatically refresh.


PAGE 1 ITEM 1
11:01:38
G
USB
TITLE
POI TRACK
NEXT
PREV
CLEAR
ADD
SEL<>
EXIT
SMALL SPEED
POI COMPASS
COMPASS
DIST TO POI
CURR POI NAME

Screen7: the COMPOSE page displays a mockup of the customisable pages, allowing the layout to be viewed before use. Note that each page also has an EXIT button at lower right.


Lat:
11:02:49
G
USB
°
'
"
<-
0
1
2
3
OK
OK
CANCEL

36° 45'

Accept?
36° 45' 0"N

Screen6: custom coordinates can be entered in either degrees/minutes/seconds or decimal degrees. They are confirmed in the currently selected display units for latitude and longitude before being displayed in the POI list.

Composing your own displays

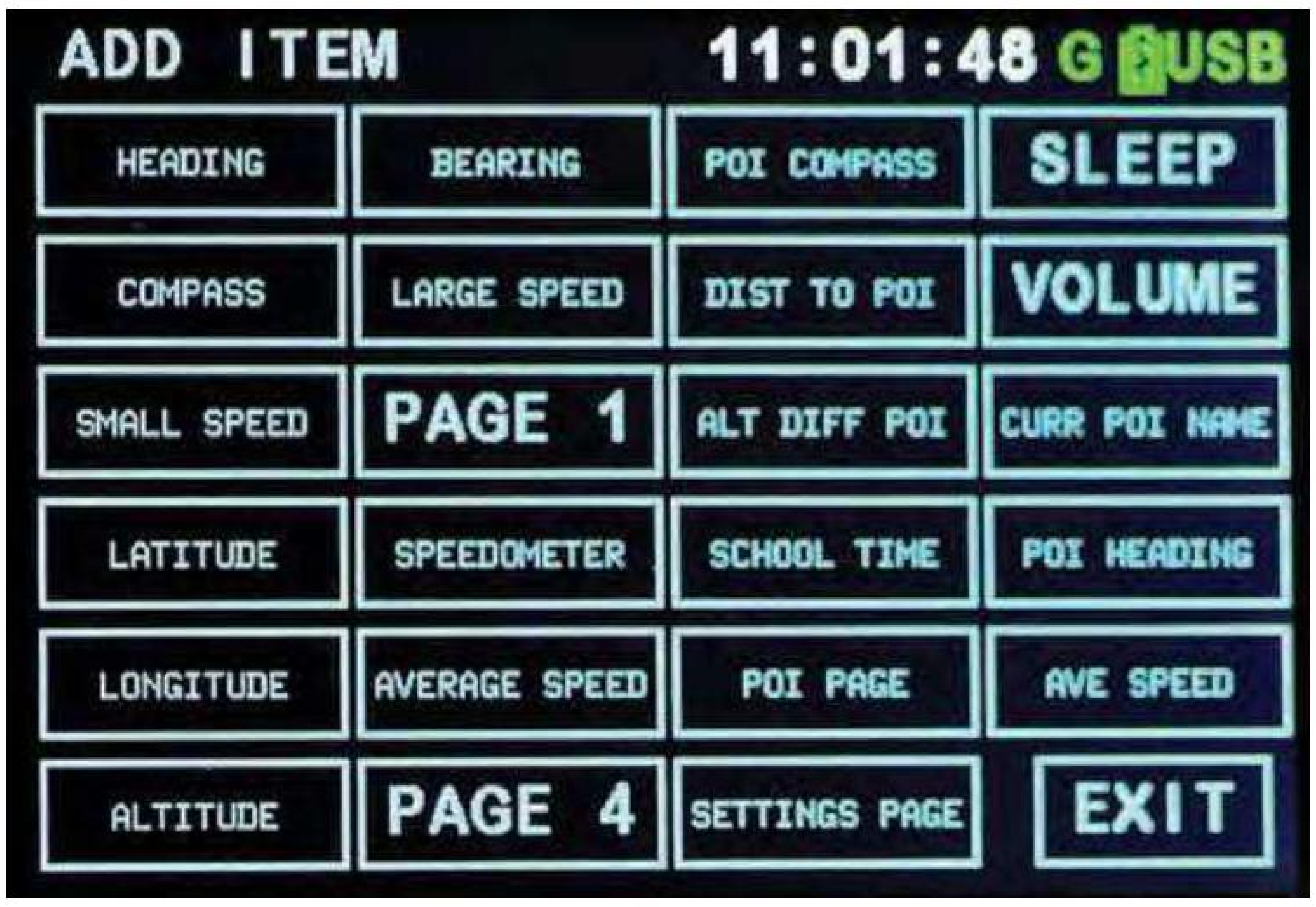
The COMPOSE page (Screen7) shows why the *GPS Computer* is so much more flexible than the *Boat Computer*. With so many people asking for specific combinations of information to be displayed, it made sense to make this as versatile as possible.

So we've designed 23 different 'tiles', each capable of displaying a small amount of information. There are four pages which can each be customised with up to six tiles each. The restriction here is mainly due to the limited amount of Flash memory available to save variables.

As for other settings, the page composition is not saved until the SAVE button is pressed on the settings page. So you can easily experiment with layouts without committing to them.

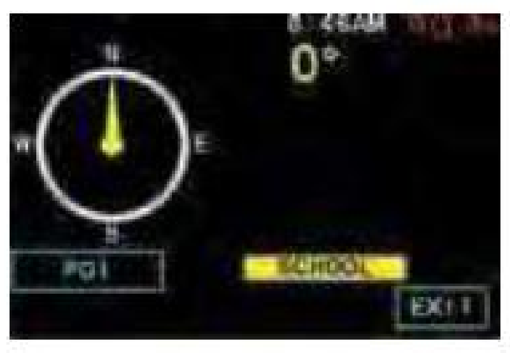
The COMPOSE page shows an overview of each page, allowing it to be edited as needed. The NEXT and PREV buttons cycle between the pages. The page and item number is shown at the top of the page, with its title below. You can edit the title by pressing the TITLE button; this title is used on the MAIN PAGE.

On each page, the currently selected tile is marked in yellow, the others in grey. Pressing inside the display area will move the selected tile, if it doesn't conflict with anything else.

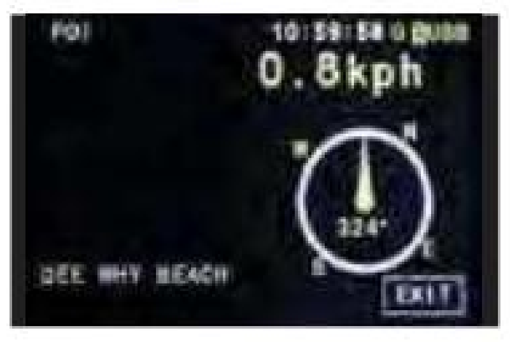

ADD ITEM
11:01:48
G
USB
HEADING
BEARING
POI COMPASS
SLEEP
COMPASS
LARGE SPEED
DIST TO POI
VOLUME
SMALL SPEED
PAGE 1
ALT DIFF POI
CURR POI NAME
LATITUDE
SPEEDOMETER
SCHOOL TIME
POI HEADING
LONGITUDE
AVERAGE SPEED
POI PAGE
AVE SPEED
ALTITUDE
PAGE 4
SETTINGS PAGE
EXIT

Screen8: there are 23 different tiles to choose from, so pretty much any combination of data can be displayed. A large speed display allows the GPS computer to be set up as a highly accurate speedometer.

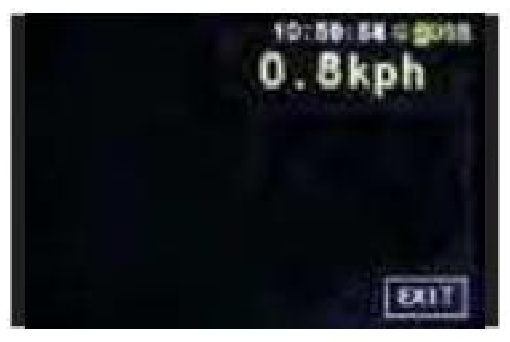
Tiles: a brief overview of each tile's features


0°
POI
SCHOOL
EXIT

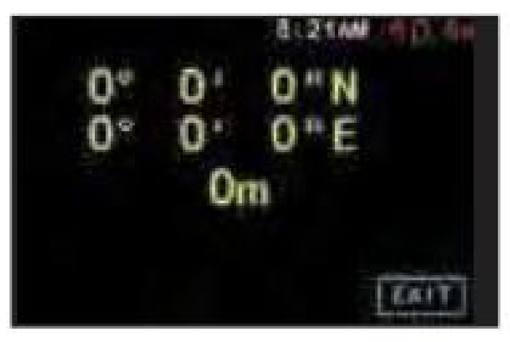
Heading: Shows a dial with top fixed at north and an arrow indicating the current track (absolute bearing direction of travel, in degrees).


0.8kph
DEE WHY BEACH
EXIT

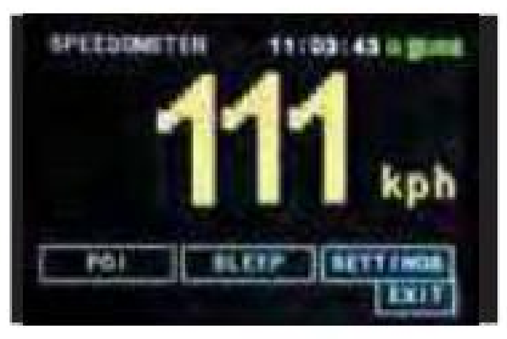
Compass: Shows a dial with the current track fixed at top and compass points rotating around to indicate the bearing. The track is also shown numerically inside the dial.



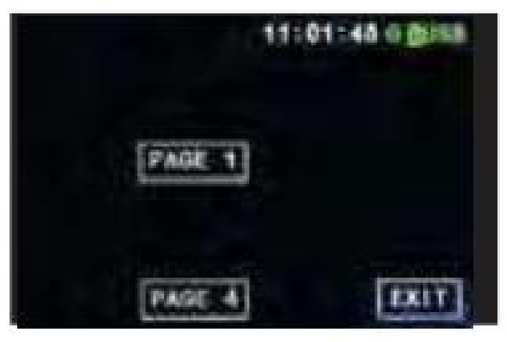
Small Speed: This text box displays the speed in text format using the current speed format and units.


0° 0' 0"N
0° 0' 0"E
0m
EXIT

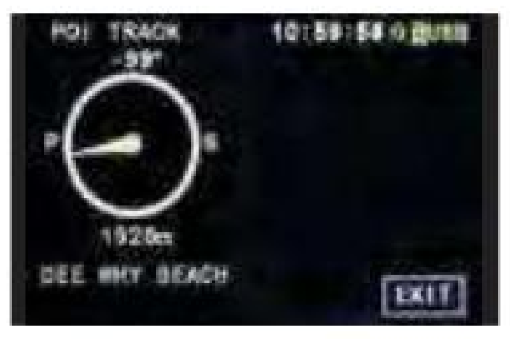
Latitude/Longitude/Bearing: Similarly, these tiles display GPS data such as latitude, longitude and altitude, also using the appropriate selected display format.


SPEEDOMETER
111
kph
POI
SLEEP
SETTINGS
EXIT

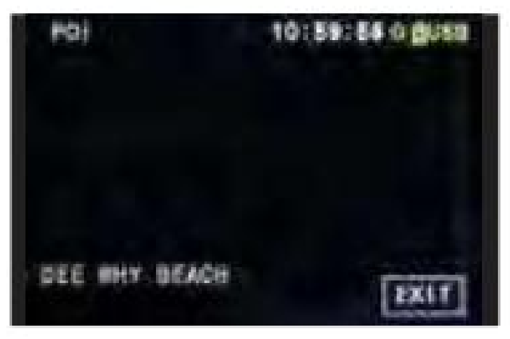
Large Speed: A text display of speed (using current units) which takes up most of the available screen.


PAGE 1
PAGE 4
EXIT

PAGE 1–PAGE 4: These add a shortcut button to the specified page. Their title will change if the page title changes.

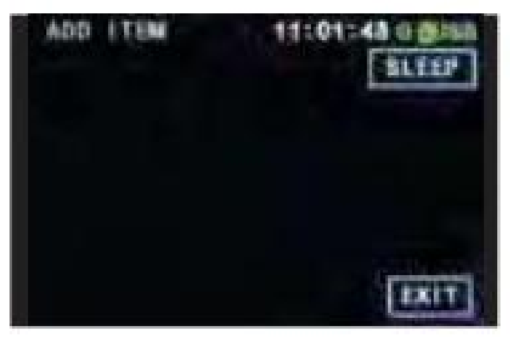

POI TRACK
DEE WHY BEACH
EXIT

POI Compass/Distance to POI/Altitude difference to POI: Show the direction (in dial format)/horizontal distance/vertical distance to currently selected POI.

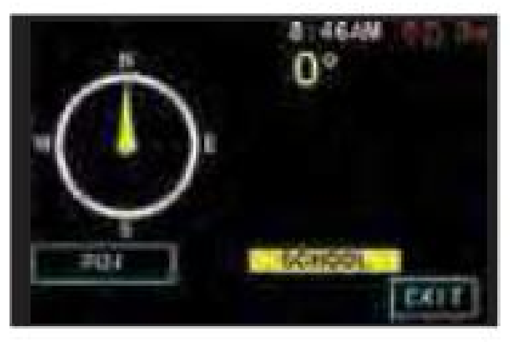

POI
DEE WHY BEACH
EXIT

POI Page/Settings Page: Shortcut buttons to the specified pages.

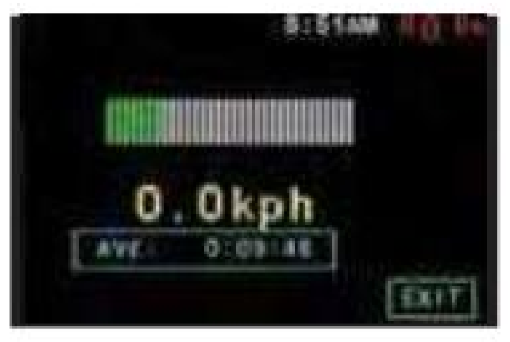
To align a tile, you can hold your finger on the touch panel and move it slowly in the desired direction. It's not quite drag-and-drop, but it's fairly intuitive.


ADD ITEM
SLEEP
EXIT

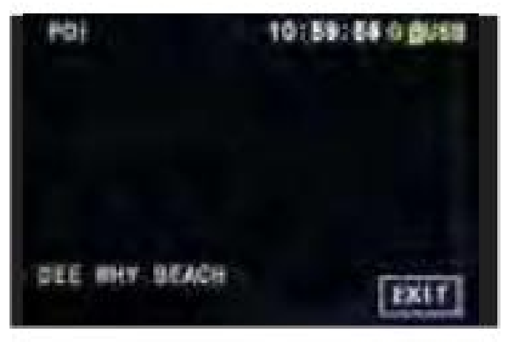
Sleep: Adds a button to put the GPS Computer into sleep mode, the same as the SLEEP button on the MAIN PAGE.


0°
POI
SCHOOL
EXIT

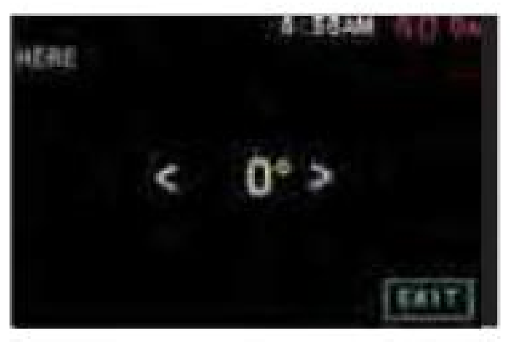
School Time: A small banner that flashes and makes a warning announcement during school hours (internally set to 8:00-9:30am and 2:30-4:00pm) according to current local time.


0.0kph
AVE:
EXIT

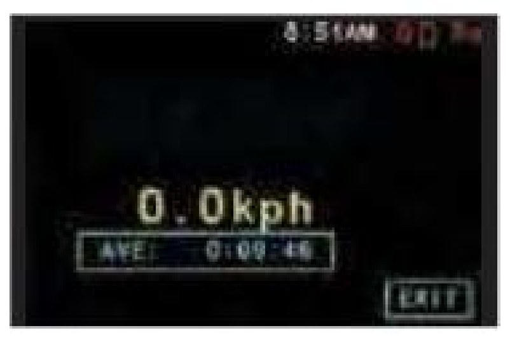
Volume: A bar graph showing the current volume level; coloured green under 100%, yellow up to 200% and red above 200%. Each bar is around 8%.


POI
DEE WHY BEACH
EXIT

Current POI name: Displays the name of the currently selected POI.



POI heading: Shows direction to currently selected POI in text format.


0.0kph
AVE:
EXIT

Average Speed: A digital average speed display. The button shows the time over which the average has been accumulated; pressing this button resets this. In other words, the average speed is measured from the time when the button was last pressed. Naturally, this doesn't accumulate during sleep or shutdown.

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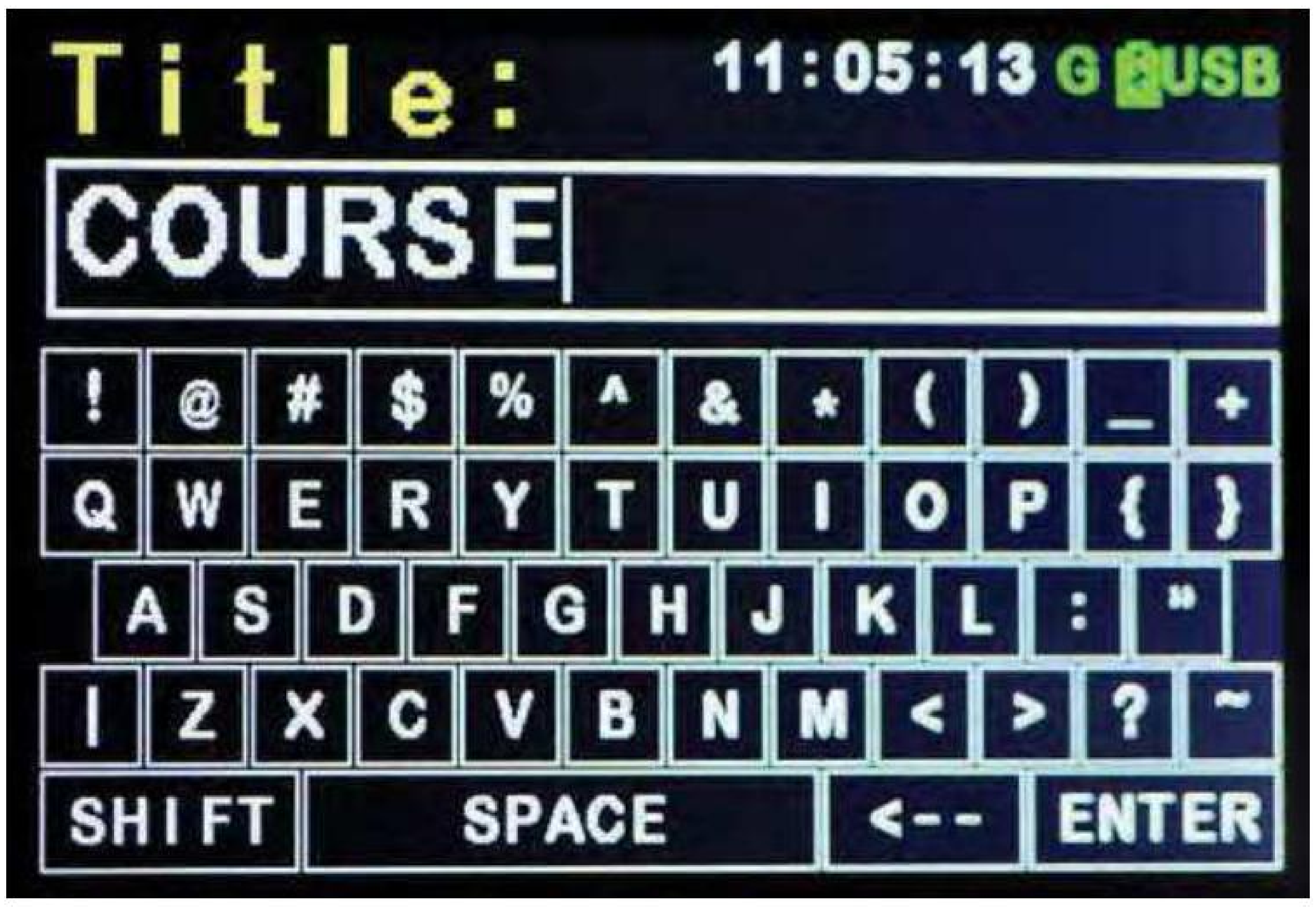
Pressing CLEAR will delete the selected tile and ADD will bring up a menu of the available tiles (Screen8). The *GPS Computer* will attempt to fit it in the current screen, and will report an error if it can't.

The algorithm does not try all possible locations, so you might have luck retrying if a tile doesn't fit the first time. Pressing SEL<> cycles between the tiles on each page.

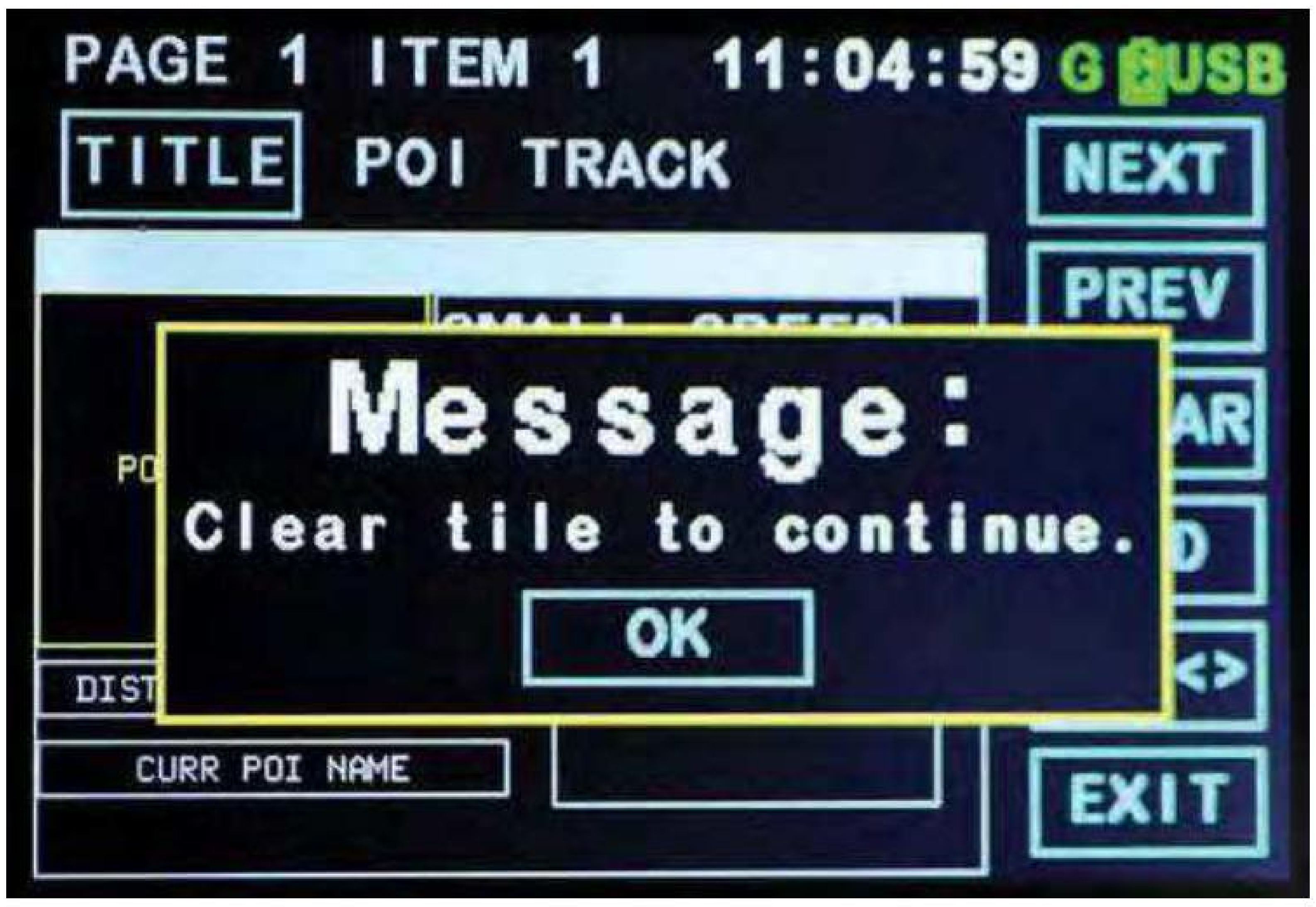


Title: 11:05:13

COURSE

G USB
! @ # $ % ^ & * ( ) _ +
Q W E R Y T U I O P { }
A S D F G H J K L : "
| Z X C V B N M < > ? ~
SHIFT
SPACE
<--
ENTER

Screen9: the larger 3.5-inch LCD and touch panel allow us to provide a full-sized keyboard to enter just about any ASCII character, except that the backtick is replaced by a degree symbol (not shown).



PAGE 1 ITEM 1 11:04:59

Message:

Clear tile to continue.

G USB
TITLE
POI TRACK
NEXT
PREV
AR
D
<>
DIST
CURR POI NAME
OK
EXIT

Screen10: a number of useful messages are provided when something interesting occurs. These are accompanied by a brief chime through the speaker to attract your attention.

Make it with Micromite

Phil Boyce – hands on with the mighty PIC-powered, BASIC microcontroller

Part 37: Installing MMBASIC on a Raspberry Pi Pico

The MMBASIC programming language has been extremely popular over the last few years, appearing at the heart of many *PE* projects (in the form of a Micromite). This month, however, we are going to show you how to install the latest version of the MMBASIC firmware into the low-cost (and readily available) Raspberry Pi Pico. The result is a module that we refer to as the 'PicoMite,' and we really do believe it will become a regular building-block in many future electronic projects. Note that the PicoMite is not a replacement for the Micromite; instead, it is an alternative that is very quick to get up and running.

So why are we so confident the PicoMite will be useful? To begin with, the PicoMite benefits from all the powerful features of MMBASIC for the Micromite, especially since it's based on the *Plus* version of MMBASIC which has more capability than the *Standard* version. Also, compared to a Micromite, the Pico module comes preassembled, so the PicoMite is a true 'plug-n-play' module. (Remember, a Micromite is essentially a Microchip PIC32 chip installed with MMBASIC but requiring the assembly of a handful of additional components to provide the relevant supply voltages, pull-ups, and connectors.)

If you are familiar with using a Micromite, then you'll find using a PicoMite a breeze, with minimal (if any) changes required to make your program code run properly.

Turning to hardware connectivity, the PicoMite provides 26 input/output pins with all the usual MMBASIC functionality: digital I/O, three analogue inputs, two serial ports, two master SPI ports, two master I²C ports, eight pairs of PWM channels, 1-wire connectivity, and an IR port. Next, clock speed: the PicoMite is configurable to run from 48MHz to 250MHz, so it is certainly no slouch when it comes to running program code.

Bearing in mind the PicoMite firmware is available as a free download, and a Raspberry Pi Pico module is available at a ridiculously low price, you can very quickly create an extremely powerful (yet easy-to-use) building block that costs well under £5.

Another big benefit of the PicoMite is that it is compatible with many of the modules that have specifically been made for (and plug directly into) the Raspberry Pi Pico. So, for example, a 2.8-inch touchscreen module (which costs around £14 and comes with a uSD (micro-SD) card socket) can be plugged directly onto the PicoMite, and with just a couple of `OPTION` settings, you have the equivalent of a *Micromite BackPack*, but with the added bonus of uSD storage for programs and/or data files. Note that there are many alternative display modules available for the Raspberry Pi Pico that will also work with a PicoMite, and this is something that we will discuss next month.

As always with MMBASIC, complex (or expensive) development tools aren't required, nor are there any complicated compiling or downloading processes to follow. All you need to get started is a computer with a terminal program (such as TeraTerm), a Raspberry Pi Pico module, a micro-USB lead (to connect the Pico to your computer), and the MMBASIC firmware file (a **.uf2** file). So, let's see just how easy it is to create a PicoMite.

Micromite code

The code in this article is available for download from the *PE* website.

MMBASIC for Pico

The original MMBASIC firmware was created by Geoff Graham a decade ago to work with specific PIC32 microcontrollers. Since then, Geoff has updated his firmware with many new features and functionality. Also, Peter Mather has assisted in pushing the capability of MMBASIC even further. Peter is responsible for migrating MMBASIC from the original PIC32 processors to the more modern ARM processors (one of which is used on the Pico – the Dual-core ARM Cortex M0). (I wish to express my thanks to both Geoff and Peter for their tireless work – MMBASIC is one of the most useful pieces of software ever created for the electronics hobbyist.)

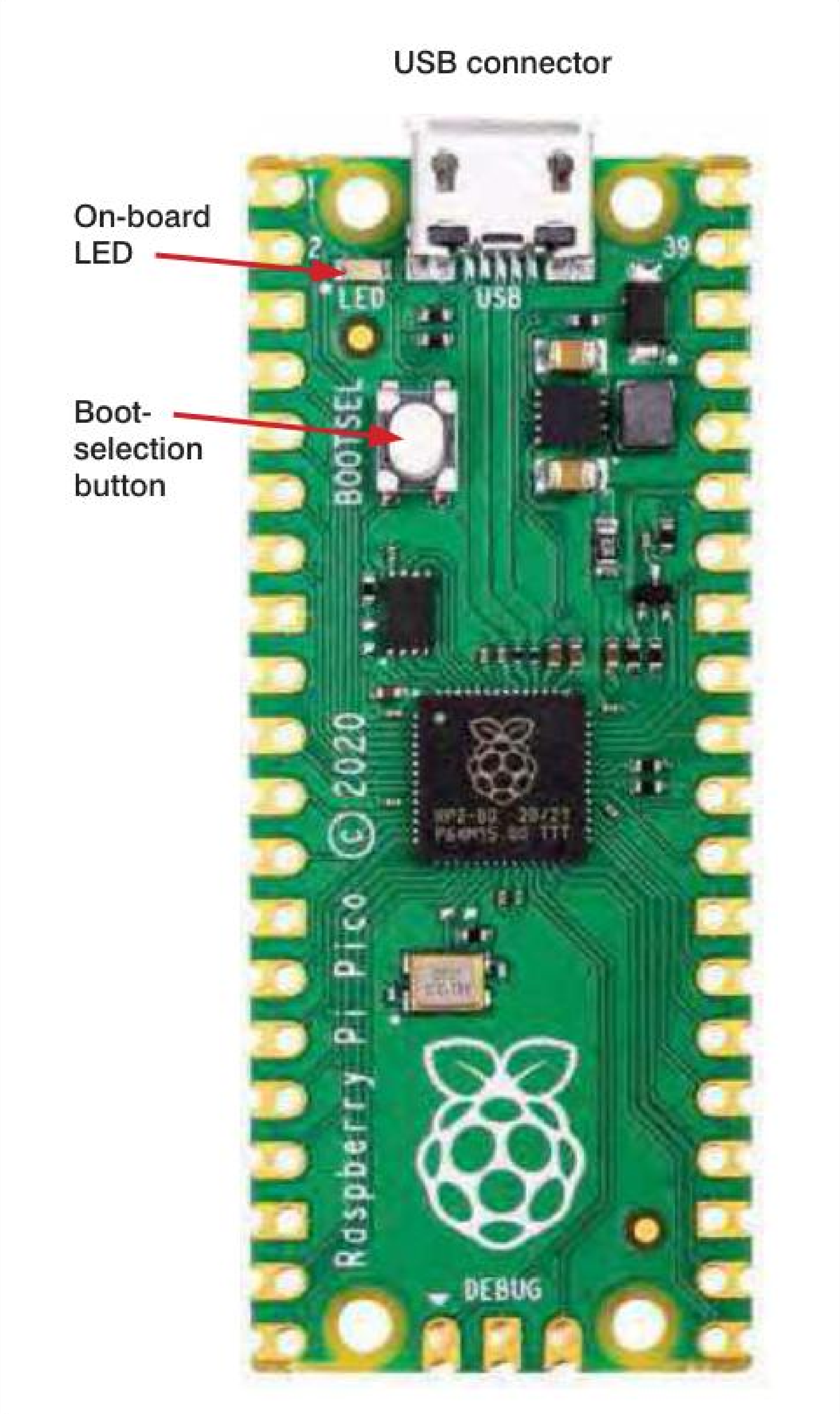
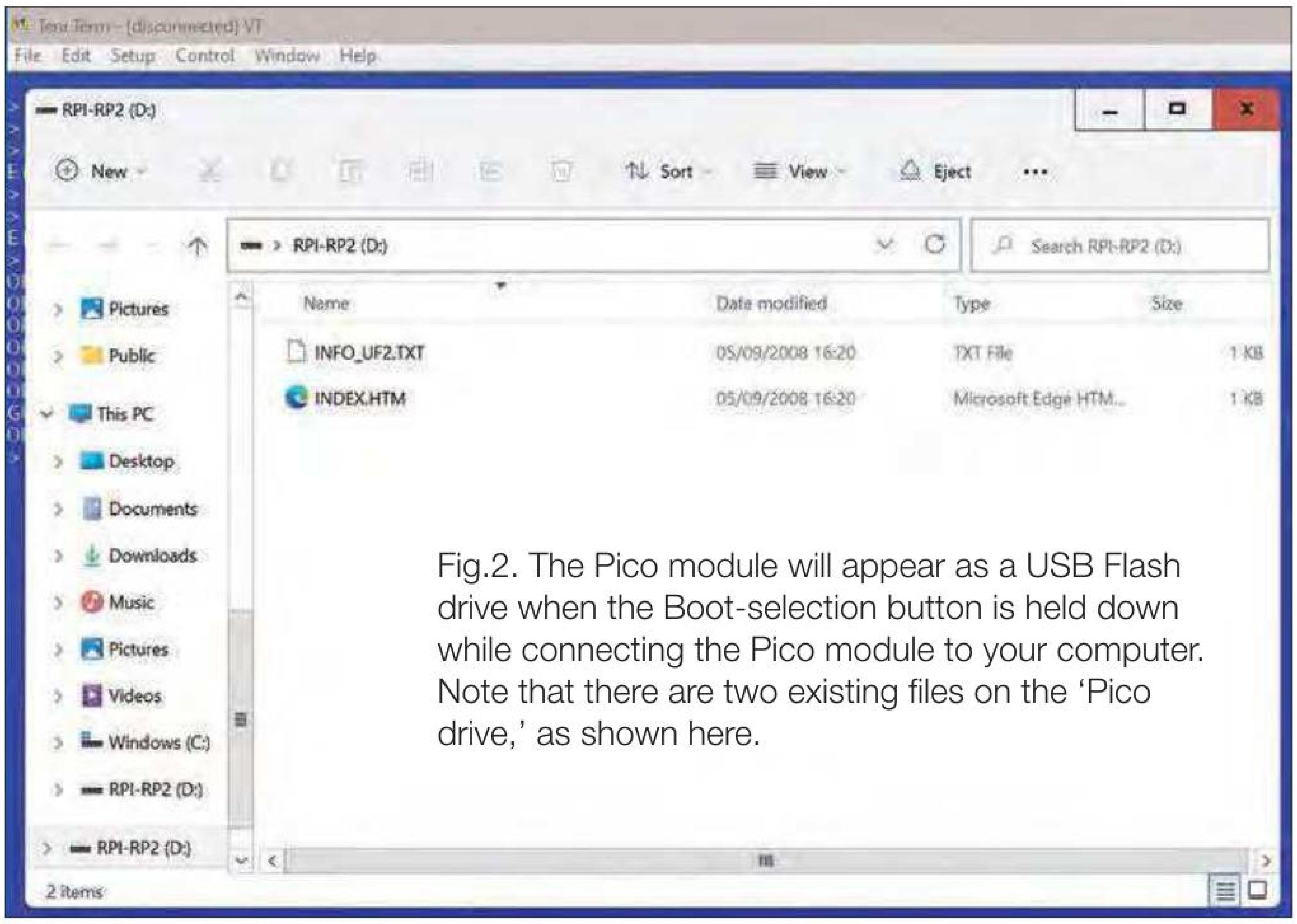


Fig.1. Location of important Raspberry Pi Pico parts used in the PicoMite firmware loading procedure.

To begin, download the PicoMite's MMBASIC firmware file (**PicoMiteV5.07.03.uf2**) from the July 2022 page of the *PE* website. Store the file in a known location – you will be loading it into the Pico shortly. Next, let's identify a few parts on the Pico module that we will use during the firmware loading process.



Name	Date modified	Type	Size
INFO_UF2.TXT	05/09/2008 16:20	TXT File	1 KB
INDEX.HTM	05/09/2008 16:20	Microsoft Edge HTM...	1 KB

Fig.2. The Pico module will appear as a USB Flash drive when the Boot-selection button is held down while connecting the Pico module to your computer. Note that there are two existing files on the 'Pico drive,' as shown here.

The Raspberry Pi Pico

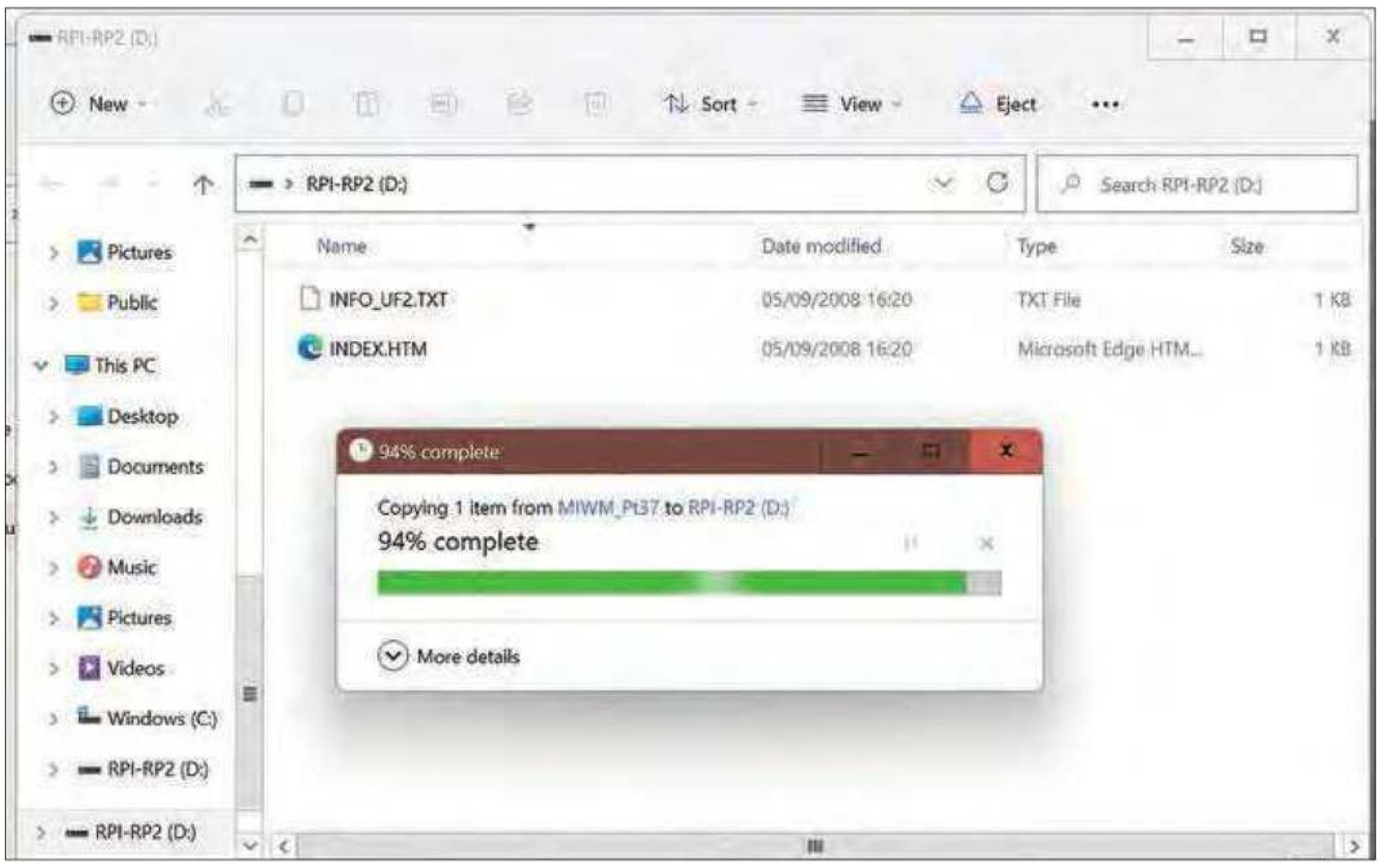
The Raspberry Pi Pico was discussed in some detail in the May 2022 edition of *PE*. However, do not worry if you missed this article since all we initially need to concern ourselves with are the locations of the following parts, as shown Fig.1:

- USB connector (a micro-USB type)
- Boot-selection button (white button labelled as 'BOOTSEL')
- On-board LED (a green LED).

Loading the PicoMite firmware

To load the PicoMite firmware onto the Pico module, you first need to put the Pico into the 'Bootloader mode'. To do this, simply hold down the boot-selection button while connecting the Pico module to your computer. This will result in the Pico powering up and appearing to the computer as an additional USB Flash drive. Your computer will automatically open a window showing a 'Pico drive' and you will see that it contains two existing files: **INFO_UF2.TXT** and **INDEX.HTM** (see Fig.2).

To load the PicoMite firmware into the Pico module, you copy the **.uf2** file downloaded previously, and paste it into the Pico drive; alternatively, you can drag and drop the **.uf2** file into the Pico drive. (Note: at the time of print, the latest version of the firmware file is named **PicoMiteV5.07.03.uf2**)



Name	Date modified	Type	Size
INFO_UF2.TXT	05/09/2008 16:20	TXT File	1 KB
INDEX.HTM	05/09/2008 16:20	Microsoft Edge HTM...	1 KB

Copying 1 item from MIWM_Pt37 to RPI-RP2 (D:)

94% complete

Fig.3. After placing the PicoMite's **.uf2** firmware file into the Pico drive, a progress bar will be displayed for a few seconds showing installation progress.

As soon as the **.uf2** firmware file is placed into the Pico drive, a progress bar will be displayed indicating that the PicoMite firmware is being installed (see Fig.3). After just a few seconds, the Pico drive window (and progress bar) will automatically close to signify that the firmware has finished loading. If you look at the on-board LED on the Pico module, you will see that it is now slowly flashing green, confirming that the PicoMite firmware is up and running. Congratulations! – you have successfully created a PicoMite and it is now ready for use.

It is worth pointing out that the only purpose of the Pico drive (initiated by holding the boot-selection button while connecting the module to your computer) is to initially install the PicoMite MMBASIC firmware (the **.uf2** file). Once installed, the firmware file will not be visible in the Pico drive. Note too that any other files moved into the Pico drive will simply be ignored.

To make things even easier, for any future PicoMite firmware updates, the PicoMite MMBASIC firmware includes the command: `UPDATE FIRMWARE` which automatically brings up the Pico drive window (on a connected computer). This means that you can house the PicoMite in an enclosure without worrying about how to access the physical 'boot-selection' button.

Now that the PicoMite is ready for use, let's do a few tests to ensure it is indeed working correctly. In addition, we advise you to download the *PicoMite User Manual* from the July 2022 page of the *PE* website. It is an extremely useful reference, including descriptions of the features built into the PicoMite.

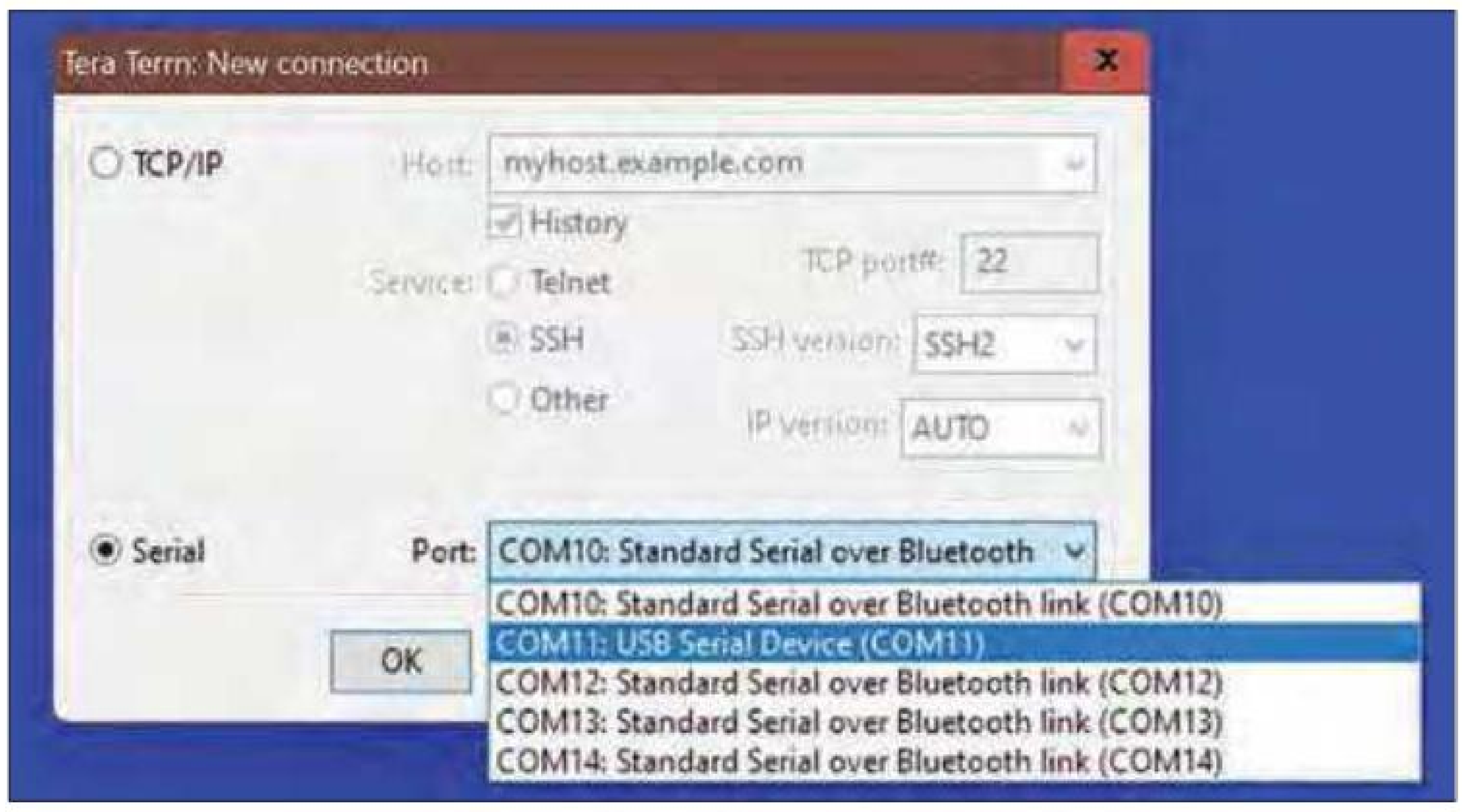
Initial testing

The PicoMite will behave as a serial port over USB, so your OS (operating system: Windows, macOS or Linux) will likely automatically detect it (especially if you're running a recent version of the OS) and hence no drivers are required. However, if you're not running a recent OS, or the PicoMite is not detected, then please refer to page 7 of the *PicoMite User Manual*.

With the PicoMite still connected to your computer, launch your preferred terminal program (ie, TeraTerm for Windows).

You will need to select the correct COM port number that the OS has assigned to the PicoMite – it will be shown in a list of possible COM ports as a 'USB Serial Device' – see Fig.4. The baud rate can be left set to the default (other than 1200). On starting the connection to the correct COM Port number, the terminal program will automatically connect to the PicoMite. Tap a few keys and ensure that you see the relevant characters displayed on the screen. Now disconnect the PicoMite, then reconnect it, and after a second or two you will see the PicoMite's welcome message displayed in the terminal program's window (see Fig.5).

Note that if the terminal program's baud rate is set to 1200 baud, then this will automatically be detected by the PicoMite and will result in the PicoMite switching into the update firmware mode; hence, for normal use, avoid using a 1200 baud rate! With everything set up, type the following three test commands at the command prompt (signified by the usual '>' character):



○ TCP/IP Host: myhost.example.com
☑ History
Service: ○ Telnet ● SSH ○ Other TCP port#: 22 SSH version: SSH2 IP version: AUTO
● Serial Port: COM10: Standard Serial over Bluetooth

COM10: Standard Serial over Bluetooth link (COM10)
COM11: USB Serial Device (COM11)
COM12: Standard Serial over Bluetooth link (COM12)
COM13: Standard Serial over Bluetooth link (COM13)
COM14: Standard Serial over Bluetooth link (COM14)

Fig.4. The PicoMite will appear as a 'USB Serial Device', and the OS will assign it a virtual COM port number. Your terminal program (in this case TeraTerm) needs to point to the correct COM port – here, COM11.

- `PRINT MM.VER` (to display the MMBASIC version number)
- `MEMORY` (to display the amount of free memory)
- `PRINT PI` (to display an approximation to the value of the mathematical constant π)

The result of the above should look like Fig.6 (note: MMBASIC commands are not case sensitive).

PicoMite I/O availability

The pins that are available for connecting to the PicoMite are summarised in Fig.7. The 26 I/O pins are shown in green and you will see that each of these pins has a reference to a 'GP' number (as used by the Raspberry Pi Pico documentation), and also a physical pin position number. For example, GP0 is pin 1, and GP28 is pin number 34. When it comes to the familiar `SETPIN` command, either pin reference can be used. Hence `SETPIN 1,DOUT` and `SETPIN GP0,DOUT` will set the same pin to a digital output.

So, if we were to connect an LED to this pin via a current-limiting resistor to ground, then we simply use `PIN(GP0)=1` (or `PIN(1)=1`) to turn the LED on, and use `PIN(GP0)=0` (or `PIN(1)=0`) to turn it off. This should be familiar to any Micromite user.

Now back to the on-board LED. Currently, the firmware is using it to show a 'heartbeat'; however, it is connected internally to GP25 (which if you refer to Fig.7 is not actually a physical pin made available for connection). So, we could take control of the on-board LED if we were to reference it as 'GP25' – let's now see this in action. At the command prompt, type the following two commands:

```
SETPIN GP25,DOUT
PIN(GP25)=1
```

And you will see that the on-board LED is now turned on. To turn it off, simply type:

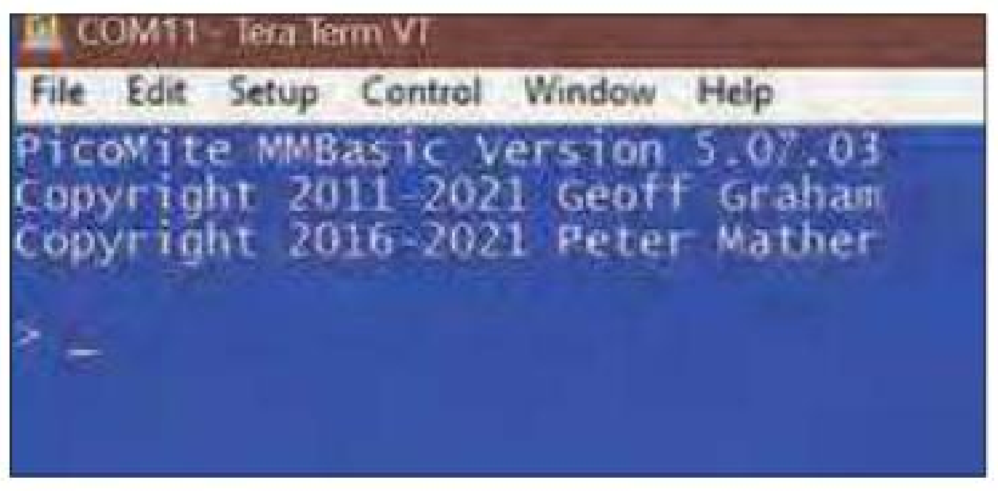
```
PIN(GP25)=0
```

Ok, this isn't too impressive, but it saved us having to hook up a resistor and an LED! And what if we wanted the on-board LED to revert back to being a heartbeat LED? Simple – just type `SETPIN GP25,HEARTBEAT`

We're not going to describe further at this point how to use the different types of I/O pins, as this article is primarily to explain how to get a PicoMite up and running. If you are familiar with I/O control on a Micromite then you will have no problem interfacing hardware to the PicoMite. Please do refer to the *PicoMite User Manual* – specifically pages 9, 25-27, and *Appendix A (serial comms)*, *Appendix B (I2C comms)*, *Appendix C (1-wire comms)*, and *Appendix D (SPI comms)* for detailed explanations and examples, and also refer to the *Commands* section (from page 79) which details the exact syntax for all commands.

I/O pin voltage

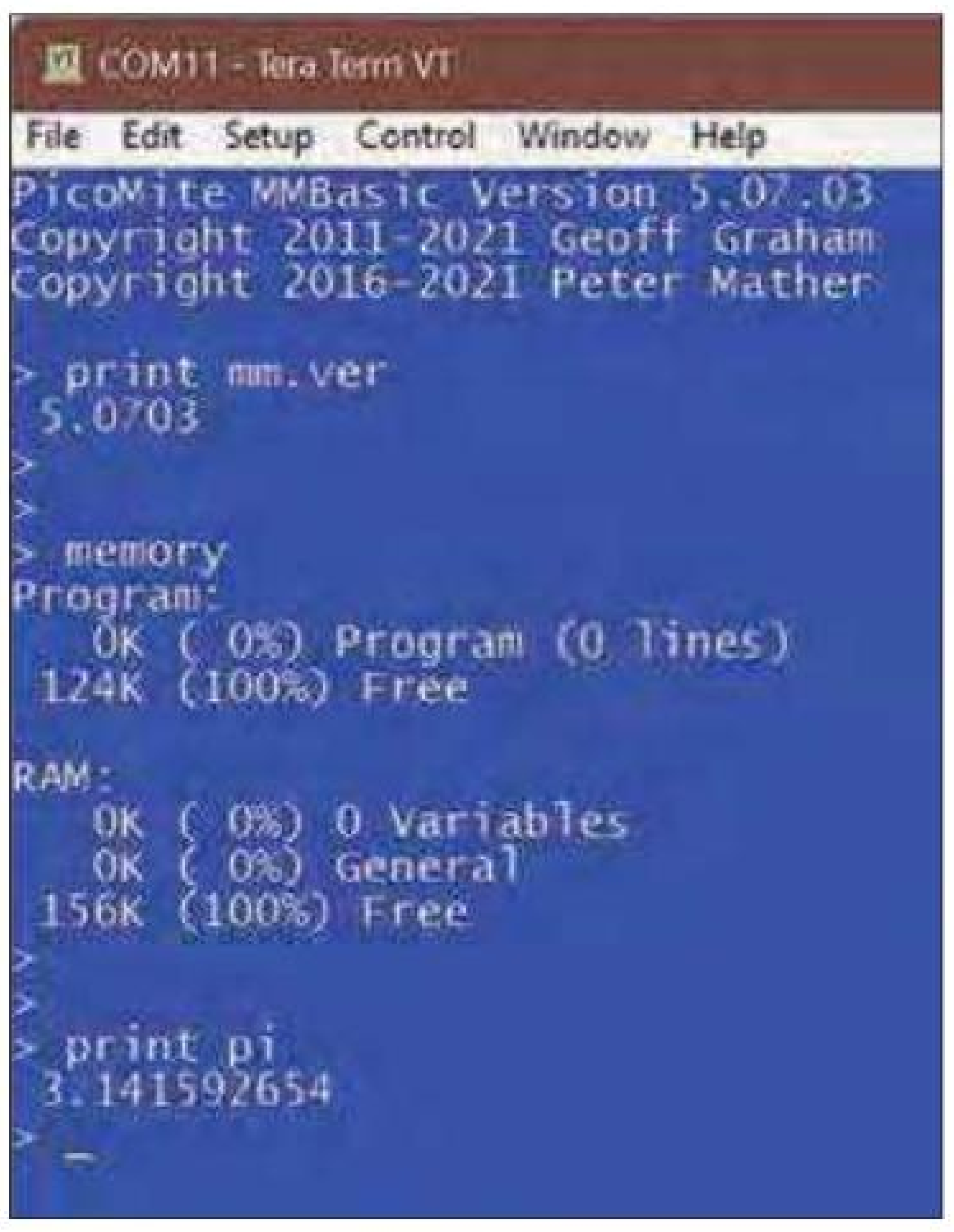
It's important to note that the maximum input voltage to any I/O pin on the Pico module is 3.6V; hence, if you are using a 5V module that needs to output a signal to the PicoMite, then you must use a level shifter. Also, the maximum source or sink current per pin is 12mA, with an overall maximum total for the module of 50mA. Exceeding any of these limits will at best result in eratic behaviour, and at worst you're likely to damage your Pico module.



```
PicoMite MMBasic Version 5.07.03
Copyright 2011-2021 Geoff Graham
Copyright 2016-2021 Peter Mather

> _
```

Fig.5. This welcome message is displayed when the PicoMite is powered up – it will be familiar to regular Micromite users!



```
PicoMite MMBasic Version 5.07.03
Copyright 2011-2021 Geoff Graham
Copyright 2016-2021 Peter Mather

> print mm.ver
 5.0703
>
>
> memory
Program:
   0K ( 0%) Program (0 lines)
 124K (100%) Free

RAM:
   0K ( 0%) 0 Variables
   0K ( 0%) General
 156K (100%) Free
>
>
> print pi
 3.141592654
> _
```

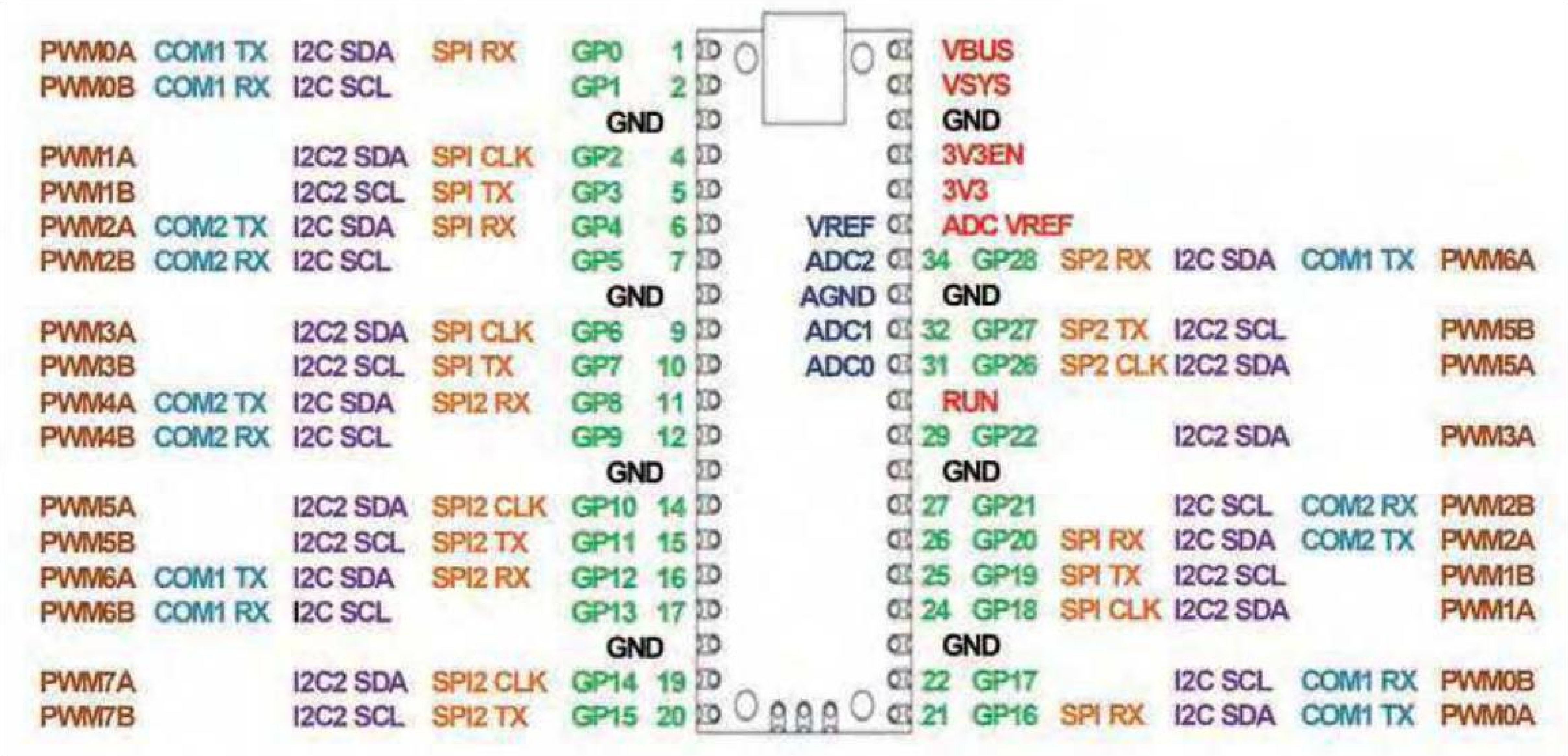
Fig.6. Three simple tests provide reassurance that the PicoMite is working correctly.

Next Time

This article has shown how quick and easy it is to create a versatile PicoMite module. Next month, we'll move on to interfacing the PicoMite to some of the many Raspberry Pi Pico display modules that are available, including 2.8-inch ILI 9341 (320x240) and 3.5-inch ILI9488 (480x320) touchscreens. In addition, we will demonstrate how to connect a much larger 9-inch SSD1963 (800x480) touchscreen, and a PS2 keyboard, to convert the PicoMite into a powerful stand-alone 'computer'.

Until then, stay safe, and have FUN!

Questions? Please email Phil at:
contactus@micromite.org



PWM0A	COM1 TX	I2C SDA	SPI RX	GP0	1			VBUS				
PWM0B	COM1 RX	I2C SCL		GP1	2			VSYS				
				GND				GND				
PWM1A		I2C2 SDA	SPI CLK	GP2	4			3V3EN				
PWM1B		I2C2 SCL	SPI TX	GP3	5			3V3				
PWM2A	COM2 TX	I2C SDA	SPI RX	GP4	6	VREF		ADC VREF				
PWM2B	COM2 RX	I2C SCL		GP5	7	ADC2	34	GP28	SP2 RX	I2C SDA	COM1 TX	PWM6A
				GND		AGND		GND				
PWM3A		I2C2 SDA	SPI CLK	GP6	9	ADC1	32	GP27	SP2 TX	I2C2 SCL		PWM5B
PWM3B		I2C2 SCL	SPI TX	GP7	10	ADC0	31	GP26	SP2 CLK	I2C2 SDA		PWM5A
PWM4A	COM2 TX	I2C SDA	SPI2 RX	GP8	11			RUN				
PWM4B	COM2 RX	I2C SCL		GP9	12		29	GP22		I2C2 SDA		PWM3A
				GND				GND				
PWM5A		I2C2 SDA	SPI2 CLK	GP10	14		27	GP21		I2C SCL	COM2 RX	PWM2B
PWM5B		I2C2 SCL	SPI2 TX	GP11	15		26	GP20	SPI RX	I2C SDA	COM2 TX	PWM2A
PWM6A	COM1 TX	I2C SDA	SPI2 RX	GP12	16		25	GP19	SPI TX	I2C2 SCL		PWM1B
PWM6B	COM1 RX	I2C SCL		GP13	17		24	GP18	SPI CLK	I2C2 SDA		PWM1A
				GND				GND				
PWM7A		I2C2 SDA	SPI2 CLK	GP14	19		22	GP17		I2C SCL	COM1 RX	PWM0B
PWM7B		I2C2 SCL	SPI2 TX	GP15	20		21	GP16	SPI RX	I2C SDA	COM1 TX	PWM0A

Fig.7. The 26 available I/O pins on the PicoMite are summarised here. For more specific details (and the use of the power pins) refer to the *PicoMite User Manual*.

Max's Cool Beans

By Max the Magnificent

Flashing LEDs and drooling engineers – Part 29

As I pen these words, I am sitting in my home office. For some reason, my poor deluded wife (Gina the Gorgeous) persists in calling this the dining room, but that's absurd because we never eat in here (there's no room because it's full of my 'stuff').

Oh, the guilt!

Sad to relate, I'm being guilted out by the animatronic robot head that's sitting on the table next to my keyboard looking balefully up at me. I can read its mind. It's thinking, 'Why aren't you writing about me telling everyone how wonderful I am?'

As you may recall from previous columns, my friend Steve Manley, who is based in the UK, and yours truly, who currently hangs his hat in the US, have been working on this auspicious artifact. If the truth be told, Steve has done all of the work, while I've spent most of the time bobbing up and down like a deranged Whac-A-Mole character in the background, offering (hopefully) useful suggestions.

Steve has been using his Fusion 365 3D CAD modelling tool (**https://autode.sk/3kMrIA7**) and his 3D printer to great effect, creating two of these bodacious beauties – one for him and one for me – cumulating (as discussed in *PE*, May 2022) with me happily holding 'my head' in my hands while chortling 'my precious' to myself (and that's not something you hear someone say every day).

Oh, the joy!

For your delectation and delight, Steve employed Fusion 365 to create some awesome, photorealistic renderings of his head (I know; this sounds as strange when I write it as it does when you read it). Let's start by perusing and pondering Fig.1, which shows a view from the back of the head.

The two round shells (far-side top) are the back of the eyes, each of which is equipped with one of our *SMAD* (*Steve and Max's Awesome Display*) boards. Since each *SMAD* boasts 45 tricolor LEDs, the result is rather spectacular, let me tell you! (You can see how just awesome these are in Steve's YouTube video **https://bit.ly/3MZ9g3q**).

Also, as we've previously discussed, each eye is connected to two small servo motors (servos), which are mounted on the upper horizontal frame. These servos allow the eyes to individually pan from side to side and tilt up and down. Steve designed a cunning implementation that allows these two movements to take place independently without interfering with each other. I continue to gasp in awe whenever I see this in action.

The small circuit board mounted in the middle of the upper horizontal frame is connected to the host processor via a 2-wire I^2C interface. This board can be used to control 16 servos (we are using only seven in this current implementation). Honestly, I have to keep reminding myself that this is a rendering and not a real-world photograph.

Now let's turn our attention to the big blue base at bottom of this image. In the foreground on the right-hand side, we see a larger, meatier servo whose arm is attached to the lower horizontal frame (we are going to have to come up with some cooler names for these structural portions of the design). This servo can be used to make the entire head pan from side to side.

Finally (for Fig.1), observe the U-shaped orange bracket that connects the lower horizontal frame with the upper horizontal frame. The way this bracket is connected to the lower horizontal frame allows the head to tilt from side-to side (this is the motion we described as 'cocking' in *PE*, March 2022). Meanwhile, the way this bracket is connected to the upper horizontal frame allows the head to tilt forward and backward. Keep these motions in mind while we take a look at Fig.2.

The main thing to observe here is the two servos that are mounted on the lower horizontal platform whose arms are connected to the upper horizontal platform. In conjunction with the aforementioned U-shaped connector and its attachment mechanisms, driving both of these servos

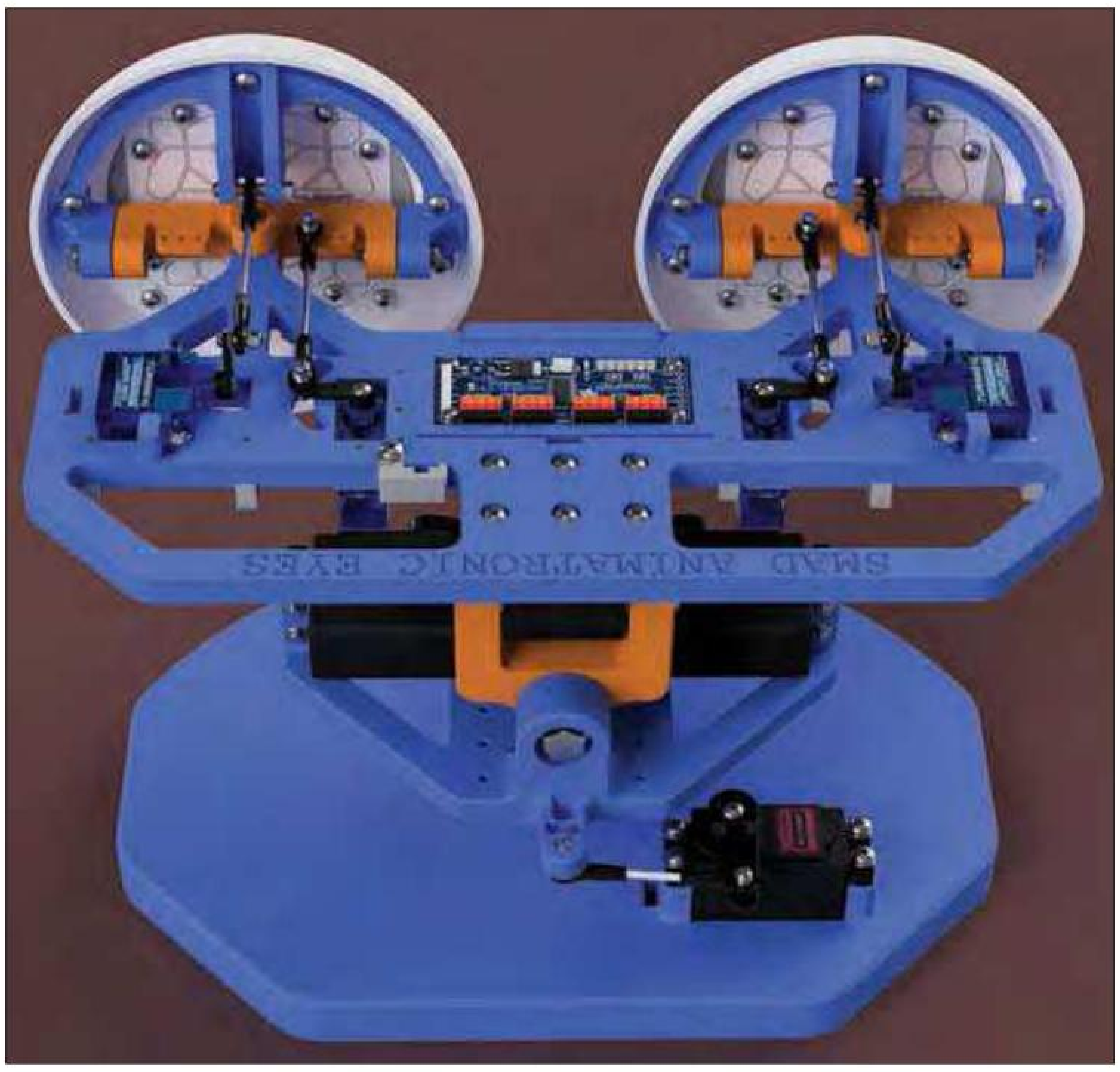


Fig.1. Rear view of the animatronic head (Image: Steve Manley)

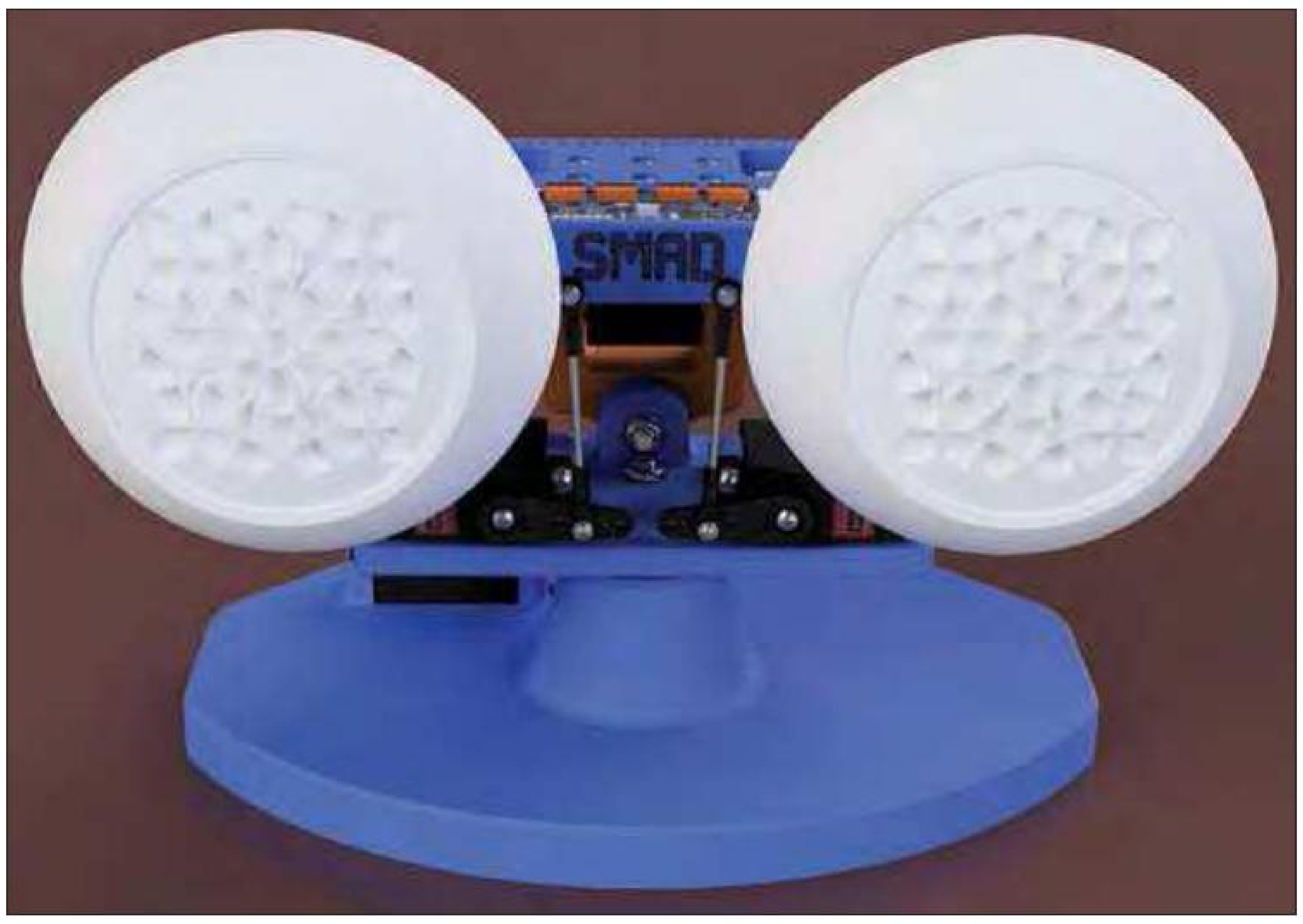


Fig.2. Front view of the animatronic head (Image: Steve Manley)

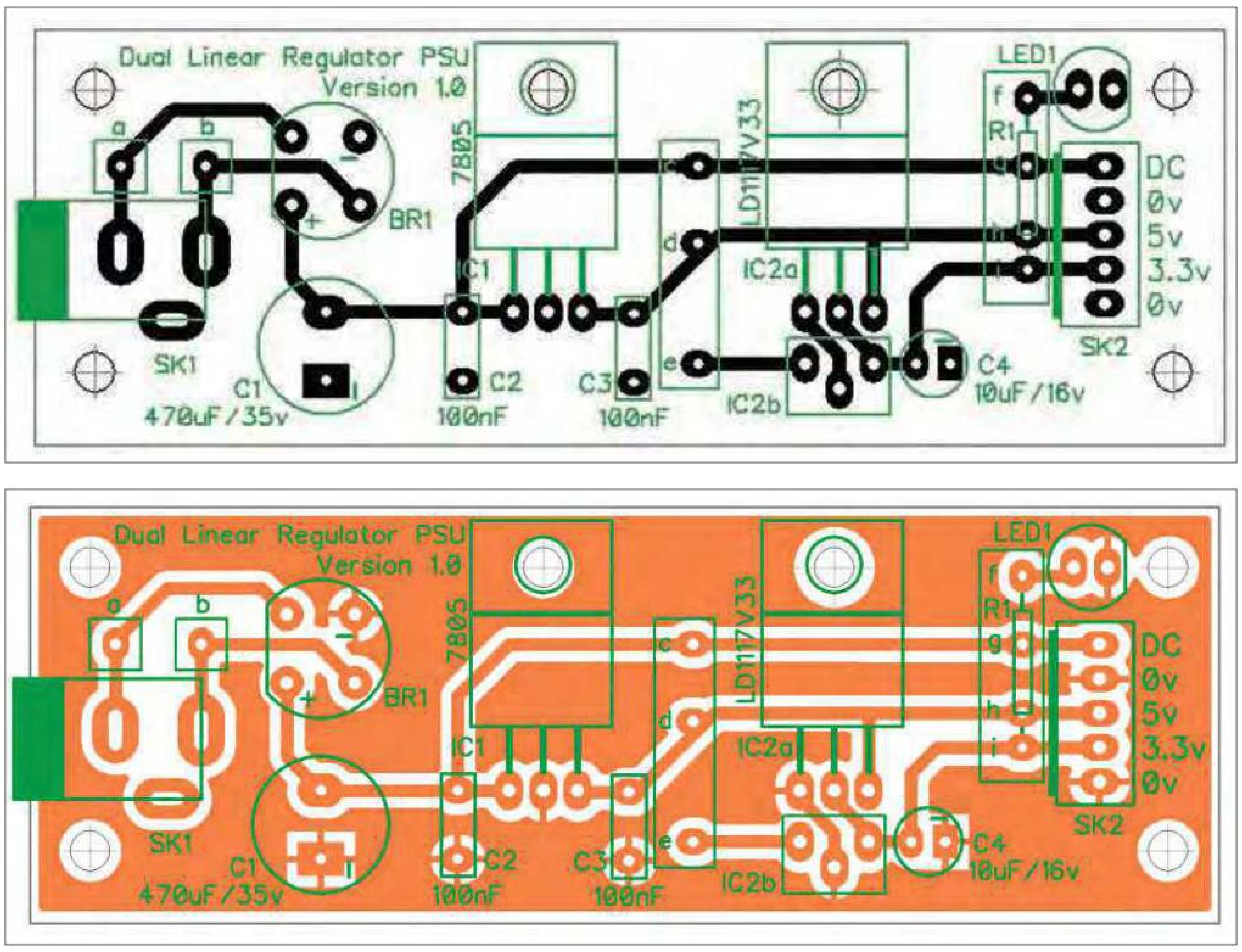


Fig.3. PCB layout for Joe Farr's handy-dandy PSU (a) (top) just showing the signal paths (top) and (b) (bottom) also showing the copper for the 0V/ground (bottom).

up or pulling them both down causes the head to tilt up or down, respectively. Alternatively, if one servo is driven up and the other is pulled down, the head will tilt to the side.

Just what is a servo?

This is a really interesting question. So interesting, in fact, that I'm going to leave answering it until my next column. The thing is that there's a lot to talk about here, including the differences between rotary motors and linear motors and stepper motors and servo motors and AC motors and DC motors and... there's even the fact that we have yet to define just what we mean by the term 'motor' in the first place (I hope to surprise you with the answer).

In the meantime, however, Steve shared some interesting information with respect to the servos we used on our animatronic head. Before we proceed, we should note that when we see something referred to as a '9g servo' or a '55g servo,' this isn't talking about how much weight the servo can lift (which is a mistake beginners may make, not least that 'lift' is not the appropriate term to use in this context). Instead, it refers to the actual weight of the servo itself. When it comes to how much work the servo can do (where 'work' has a specific meaning in physics), this is where we move into the concept of torque, which is another tortuous topic about which we will talk when next we meet. But I fear we are wandering off into the weeds, so let's return to Steve, who spake as follows:

I used four 9g servos to implement the pan-and-tilt on the eyes. Also, I used three 55g servos to implement the pan-and-tilt on the head. In the case of the 9g servos, I started with Longruner KY66s with plastic gears from Amazon (**https://amzn.to/3MU6KeI**). Unfortunately, these turned out to have inconsistent quality. One or two worked fine, but the others were either very noisy or 'un-smooth' in operation.

When it came to the 55g servos, my original choice was Diymor MG996R devices, also from Amazon but with metal gears (**https://amzn.to/3KXMtU6**). These turned out to be just as inconsistent as the original 9g servos. Plus, the range of movement for a given input range was also inconsistent, which meant the pitch and roll movements of the animatronic head were lopsided. As a result, I would not recommend or use these Amazon-sourced servos again.

Eventually, I came across HobbyKing, which is based in the EU and has a wide range of better-quality servos available (**https://bit.ly/37oeJS3**).

I Googled for a good all-round 9g servo and came up with the popular Hextronic HXT900s (**https://bit.ly/3kN0DNe**). These are reasonably priced and consistent plastic-geared servos that worked quite well.

I also purchased some metal-geared Turnigy TGY-50090 servos of equivalent size (**https://bit.ly/37pEFNb**). These are very nice. They are more expensive and maybe a tad noisier than the others, but they're the smoothest of all and they are my preferred choice when it comes to 9g servos.

I also looked up alternative 55g servos and picked the Tower Pro MG996R devices (**https://bit.ly/3yC8Lsf**). This is another metal-geared servo that seems to be consistent and smooth in operation, and not too noisy.

Each size or class of servo that I have evaluated seems to be consistent with respect to their dimensions and were therefore interchangeable. I cannot speak for other servo brands and models, which may have different dimensions. I have to say that finding fully informative data sheets for servos proved to be quite a challenge.

Got a good idea?

I don't know why, but for some reason I can envision you reading this column saying to yourself, 'I have a really good idea for Steve and Max's animatronic head, but I don't know if I have the energy to email Max and tell him.'

Well, maybe I can induce you to rouse yourself out of your comfy chair and stagger over to your computer to share your cunning concept. I know, let's have a competition. You will find the details following the next topic, which is...

The return of the PSU

I fear that I am obliged to commence this portion of our discussions by saying that I feel like an old fool. 'But where are we going to find an old fool at this time of the day?' I hear you cry (the old jokes are the best ones).

Why am I charged with chagrin and wallowing in mortification? Well, in my previous column (*PE*, June 2022), I waffled on about the power-supply circuit my

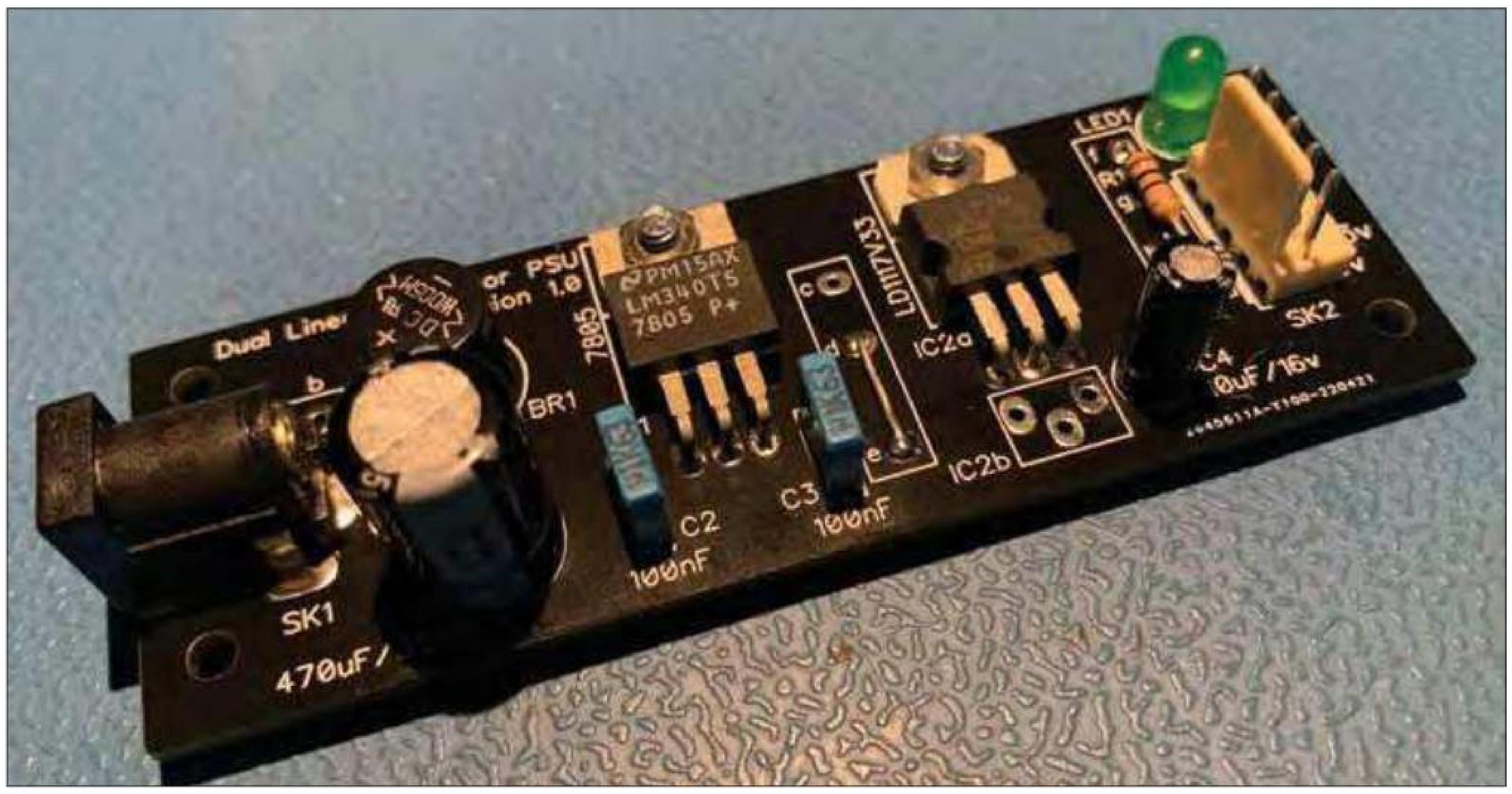


Fig.4. The assembled PSU.

chum Joe Farr implemented on the PIC Programing and Test board he designed for your humble narrator. As part of this, Joe created a handy-dandy standalone PSU board that I described in loving detail, including showing the printed circuit board (PCB) layout (Fig.3a).

You may recall that Joe designed this as a single-sided board to facilitate those who like to create their own boards at home (as described in the aforementioned column – Joe kindly provided the design files for you to download if you wish to build your own boards or have them fabricated for you).

The thing is, when I happened to glance at the layout a little later, I suddenly realised that I couldn't see any copper connecting the 0V/ground signals together (look at the lower pins on the capacitors and the 0V signals on the SK2 connector in Fig.3a, for example).

I immediately emailed Joe querying why he had done it this way and asking if we were supposed to wire these connections by hand. Once he'd picked himself up off the floor and stopped laughing, Joe explained that there was no hand-wiring involved and that he'd simply omitted that part of the copper for clarity. He also sent another version of the layout showing all of the copper (Fig.3b). All of this was so obvious that I would have realised it had I paused for thought, which explains why I was left feeling so silly.

A captivating competition

As I previously noted, the standalone PSU board was just something we implemented for fun. As part of this, Joe had five boards fabricated and he assembled one for me to play with (Fig.4), which means there are four bare boards going spare.

Joe suggested that we offer these unpopulated boards as prizes in a little competition. I discussed this with the illustrious publisher of *PE*, Matt Pulzer, who is a legend in his own lunchtime. Between us, we agreed that there should be four categories (one per board) as follows:

- Best mechanical addition
- Best lighting effect for the eyes
- Most interesting sensor scenario
- Where do we go from here?

I think the first item speaks for itself. In the case of the best lighting effect for the eyes, remember that we have 45 individually controllable tricolor LEDs for each eye (Fig.5), so what awesome effect can you come up with (all you have to do is provide a description because it will be my problem to make it happen). When it comes to the most interesting sensor scenario, what we're thinking of here is using some sort of sensor to detect what's happening in the world around the head and for the head to respond in some way (again, you only have to describe this, not implement it). The final category is wide open – what should do we with this project going forward?

Your mission, should you decide to accept it, is to email me with your ideas (you can find my address at the end of this column). The suggester of whichever idea most tickles my fancy for each category will receive one of Joe's unpopulated PSU boards (I'll email the winners to request shipping details).

It's a small world

When I was a kid, I often heard older people saying, 'it's a small world.' This expression is used to indicate surprise when you meet someone you know in an unexpected place. It may also be used if, while talking to someone, you discover that you share a friend or acquaintance. Well, the older I get, the more I find this saying to be true.

For example, as part of a project that I'm currently working on, I recently took delivery of an OMTech 40W CO2 Laser Engraver/cutter, model DF0812-40BG (**https://amzn.to/3vQqMRG**). This really is rather tasty. I would like to take this opportunity to say that the manual that accompanied this machine was amazingly informative and that it helped me get up and running quickly and easily. Unfortunately, I can't say this because there was, in fact, no manual accompanying the machine (to be fair, I did track one down later on their website).

I have a friend (stop laughing, it's true), who we will call Rick (because that's his name). Rick lives in Birmingham, Alabama, which is about 90 miles south of the town I call home. Since Rick, who is recently retired, is great at this sort of thing, I asked him if he'd like to take a road trip to help me set things up.

It only took us a couple of hours and a few trips to a local hardware store to pick up some bits and bobs, like a 5-gallon bucket to hold the distilled water to cool the laser (just one of the things I wasn't expecting) before we had the hardware portion of the operation ready to rock-and-roll.

A little research on the web suggested that the supplied software wasn't up to snuff. Fortunately, it was around 6:00pm on a Tuesday evening, which is the day my local community makerspace – Makers Local 256 – is open to the public (**https://bit.ly/3sfTPMc**), so we decided to amble over to see if there was a laser expert available to provide advice. There was! He's going to visit my office next week and help me with the software part of the exercise (I will tell you more about this in my next column).

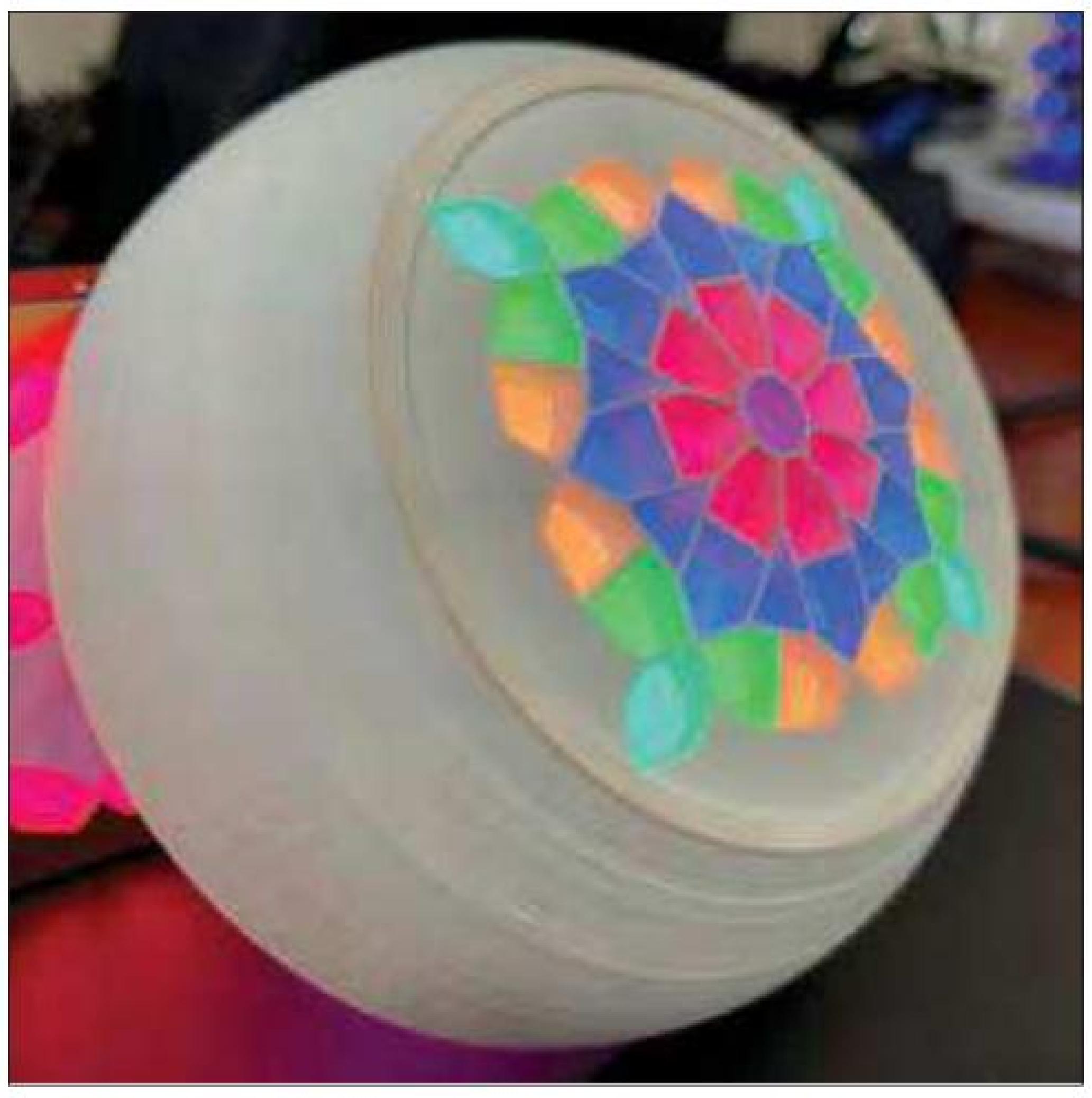


Fig.5. One of the animatronic head's eyeballs (Image: Steve Manley)

The reason I'm waffling on about this here is that, on the way back from the makerspace, I regaled Rick with my recent adventures in PICs. As I mentioned in my previous column, Joe in the UK had introduced me to the Proton IDE (integrated development environment) and the Positron PIC BASIC Compilers created by my new hero, Les Johnson. The reason I say 'compilers' (plural) is that Les supplies different compilers for 8-bit and 16-bit PICs, but both are included in the £39.99 asking price and the IDE automatically uses the appropriate compiler based on the PIC chip you select.

I was going to say that it's a long time since I programmed in BASIC, but I just remembered that, as I discussed in one of my *Cool Beans Blogs* (**https://bit.ly/3KTwHJO**), a couple of years ago I purchased a modern incarnation of the legendary Commodore 64 called THEC64 (**https://bit.ly/3smaoGu**), which features a high-definition output via HDMI, a classic style joystick, and 64 built-in classic games, plus it allows you to program in BASIC, but we digress...

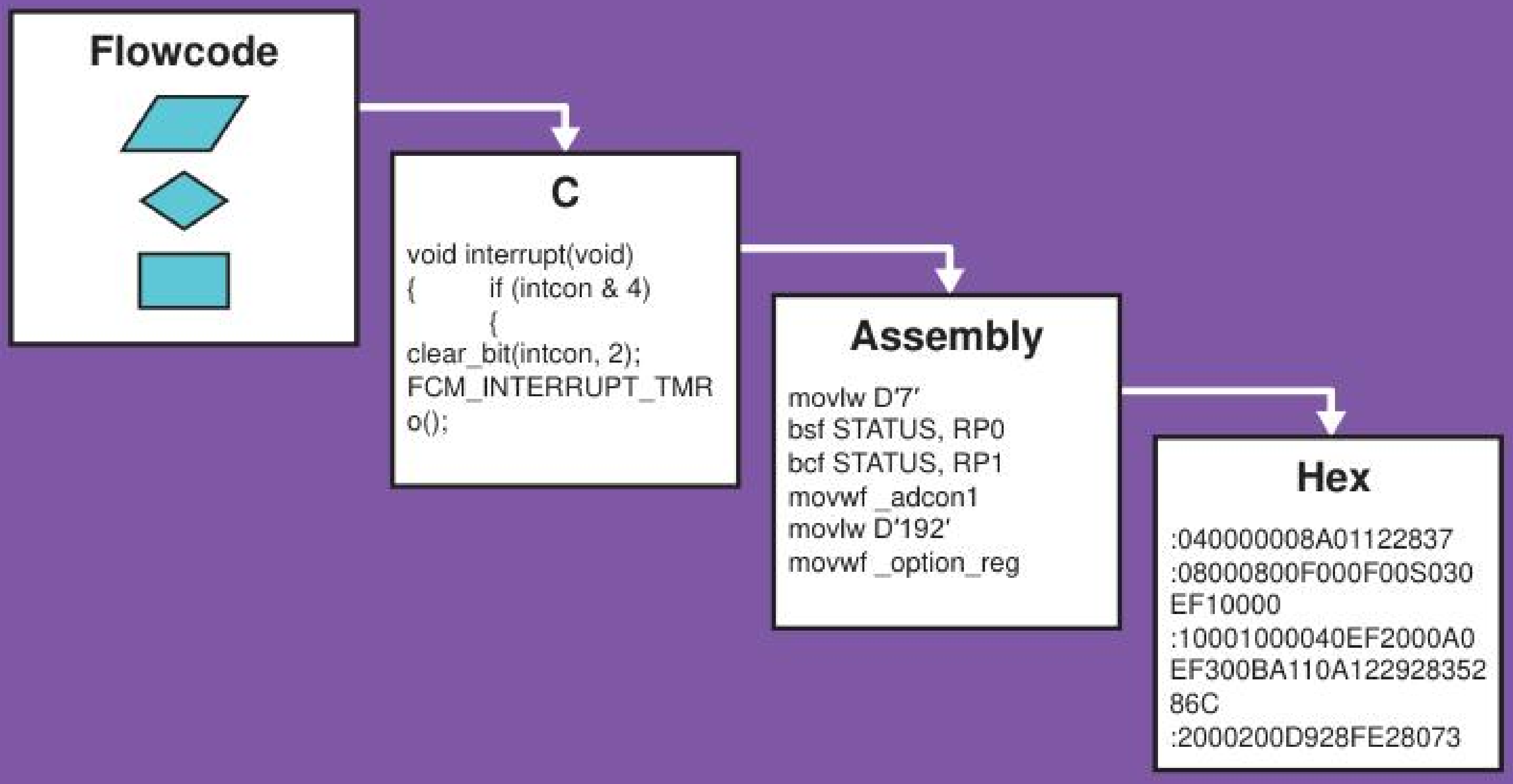
The point of all this is that, when I mentioned to Rick that I had discovered the awesome power of Positron PIC BASIC Compilers, he immediately responded that he was a devotee himself, that Les Johnson was well known to him, and that they were in regular communication via the Positron BASIC Community forum (**https://bit.ly/3vRjRHO**).

What can I say, except that it really is a small world? OK, now it's your turn. Remember that I love to receive your comments, questions, and suggestions. Also, that I'm looking forward to receiving your entries to this month's competition regarding my animatronic head. Until next time, have a good one!

Cool bean Max Maxfield (Hawaiian shirt, on the right) is emperor of all he surveys at **CliveMaxfield.com** – the go-to site for the latest and greatest in technological geekdom.

Comments or questions? Email Max at: **max@CliveMaxfield.com**

Flowcode Graphical Programming


Flowcode
C
void interrupt(void)
{ if (intcon & 4)
{
clear_bit(intcon, 2);
FCM_INTERRUPT_TMRo();
Assembly
movlw D'7'
bsf STATUS, RP0
bcf STATUS, RP1
movwf _adcon1
movlw D'192'
movwf _option_reg
Hex
:040000008A01122837
:08000800F000F00S030EF10000
:10001000040EF2000A0EF300BA110A12292835286C
:2000200D928FE28073

Programming with Flowcode – Part 4: Designing a Digital Clock

We are going to start a new project this month. It will build on ideas from previous columns but also introduce two new and very useful components, plus we'll refresh some earlier programming ideas and incorporate some new ones.

First a little housekeeping – as always, all the parts in this project come from the free-to-use component library of Flowcode, so you can build this in Flowcode without making any code purchases. For more details, do see the Flowcode try-before-you-buy box at the end of this article.

Project overview

It's no secret that one of the most useful and widely used applications of digital technology is timekeeping. So, for our next Flowcode project we will assemble and program a system to create a simple digital clock. This will help to extend your understanding of Flowcode and illustrate ideas and techniques you can use in your designs.

The Flowcode *Digital Clock* hardware will consist of four main parts: a microcontroller, a display, an RTC module and a keypad. The microcontroller is our usual Arduino Uno clone, the RedBoard. The display will be the same 16x2 LCD we used last month. The two new components are the RTC (real-time clock), an inexpensive module based on a DS1307, DS3231 or DS3232 IC, and a simple, low-cost membrane keypad.

Whichever IC the RTC module uses, it keeps time with a precisely repeating pulse (the 'clock') plus some initialising set-up data which is stored in non-volatile SRAM. It uses the stored data and clock pulse to accurately calculate the time and date, which are then sent out via its I²C bus. The module generates seconds, minutes, hours, day, date, month and year information. The end of the month date is automatically adjusted for months with fewer than 31 days, including corrections for leap year up to 2100. Plus, it works with the 24-hour or 12-hour format via an AM/PM indicator.

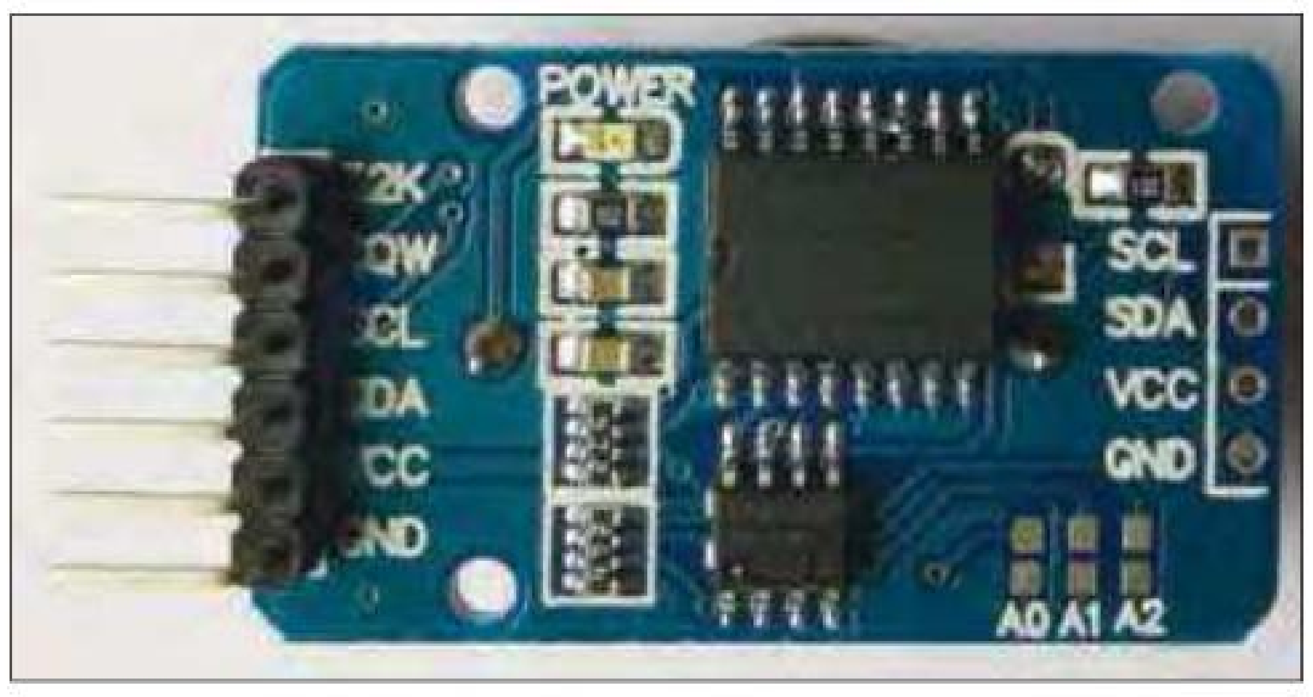

POWER
32K
SQW
SCL
SDA
VCC
GND
SCL
SDA
VCC
GND
A0 A1 A2

Fig.1. Typical inexpensive RCT module based on the DS3231 IC

You can also set alarms. So, all in all, it's quite a handy device for clock builders.

As explained, the free Flowcode RTC component can support each of the DS1307, DS3231 or DS3232 ICs, and I used one with the DS3231 – see Fig.1. At the time of writing, you can buy a module based on this IC for under £5, for example eBay item 125318625863, but there are many other vendors.

Naturally, you need a way to set up and initialise the RTC with the current time/date, and to do that we will use a membrane keypad. These simple and inexpensive devices are a great way to interface with digital projects, and learning how to use it in this Flowcode project will help you in a host of other designs. I used the 4x4 type shown in Fig.2. There are many sources for these; for example, eBay item 275255946762.

This won't be a PIC project. Unlike more modern PIC devices, the free Flowcode PIC16F88 we have been using does not support the I²C protocol, which rules it out for communication with our RTC of choice.

As well as the two new Flowcode components, we will also use some new Flowcode programming techniques, in particular we will learn about:

- Byte-to-string conversion
- Global and local variables
- The difference between == and =
- The logical operators `&&` and `||`, plus comparison operators > and <
- Calling a User Macro and passing input parameters
- Returning a value from a User Macro.

Naturally, all the Flowcode for this project can be downloaded from the July 2022 page of the *PE* website, and don't forget that if you get stuck there are helpful forums at: **https://flowcode.co.uk/forums/index.php**

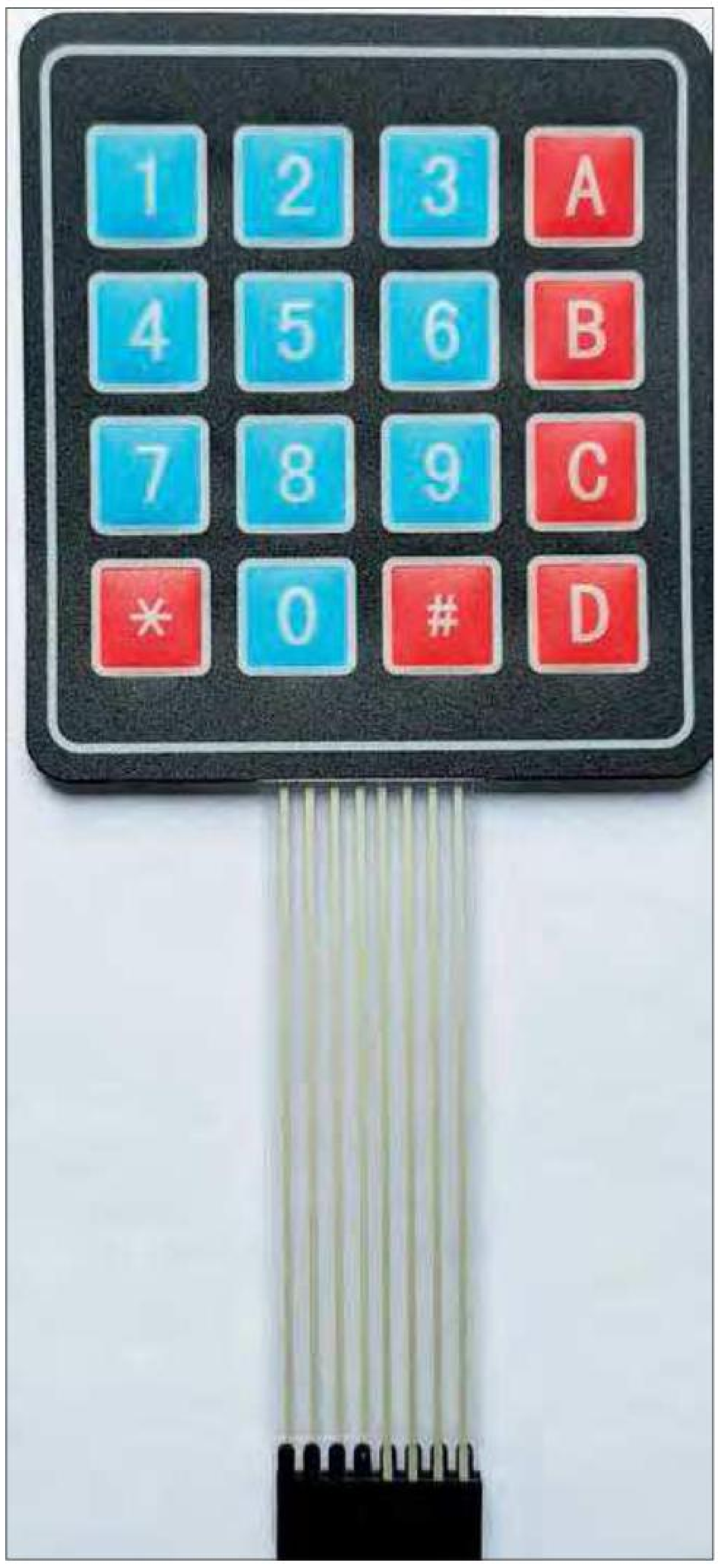

1
2
3
A
4
5
6
B
7
8
9
C
*
0
#
D

Fig.2. 4x4 membrane keypad.

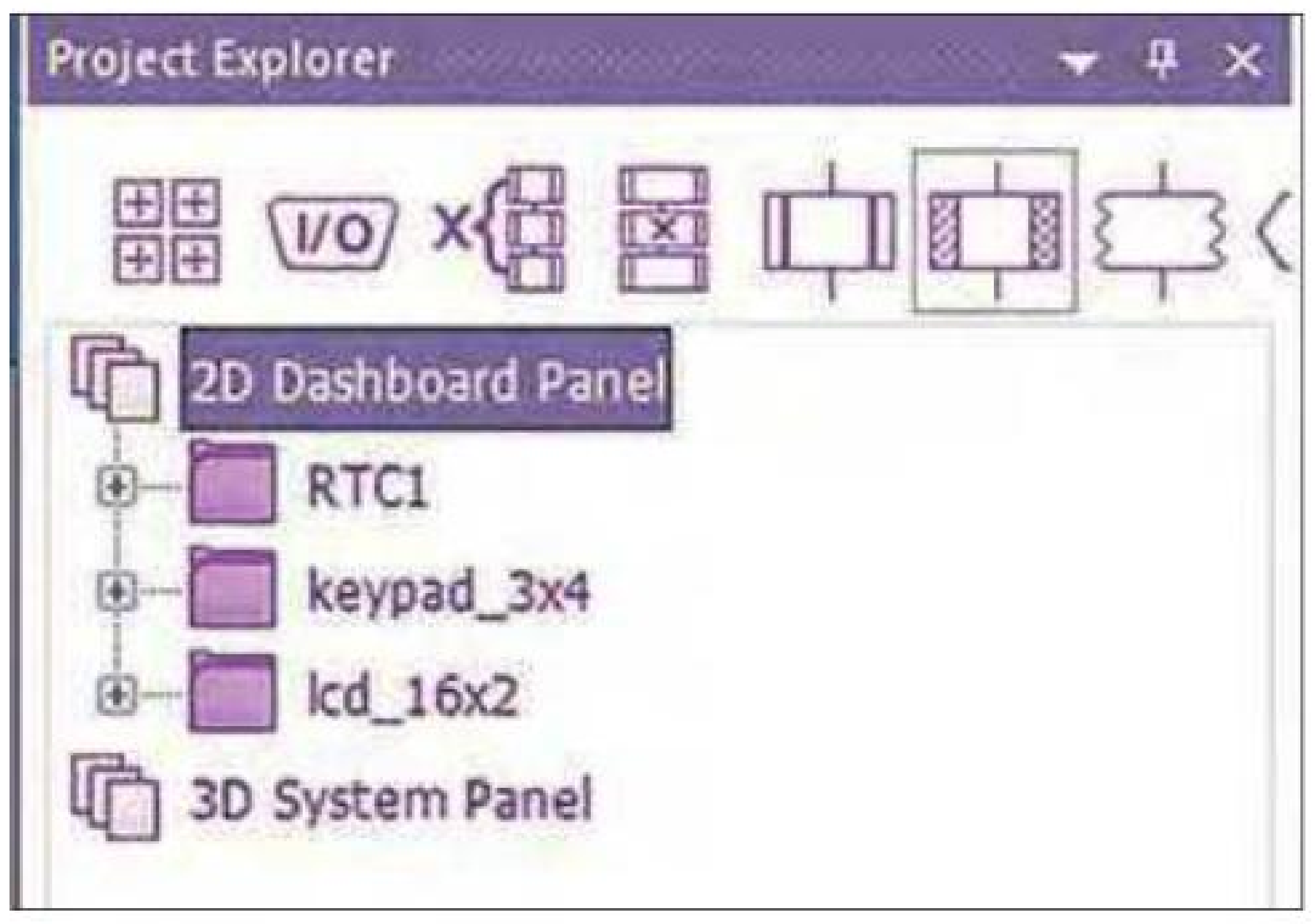

Project Explorer
I/O
2D Dashboard Panel
RTC1
keypad_3x4
lcd_16x2
3D System Panel

Fig.3. Project Explorer with the main components added.

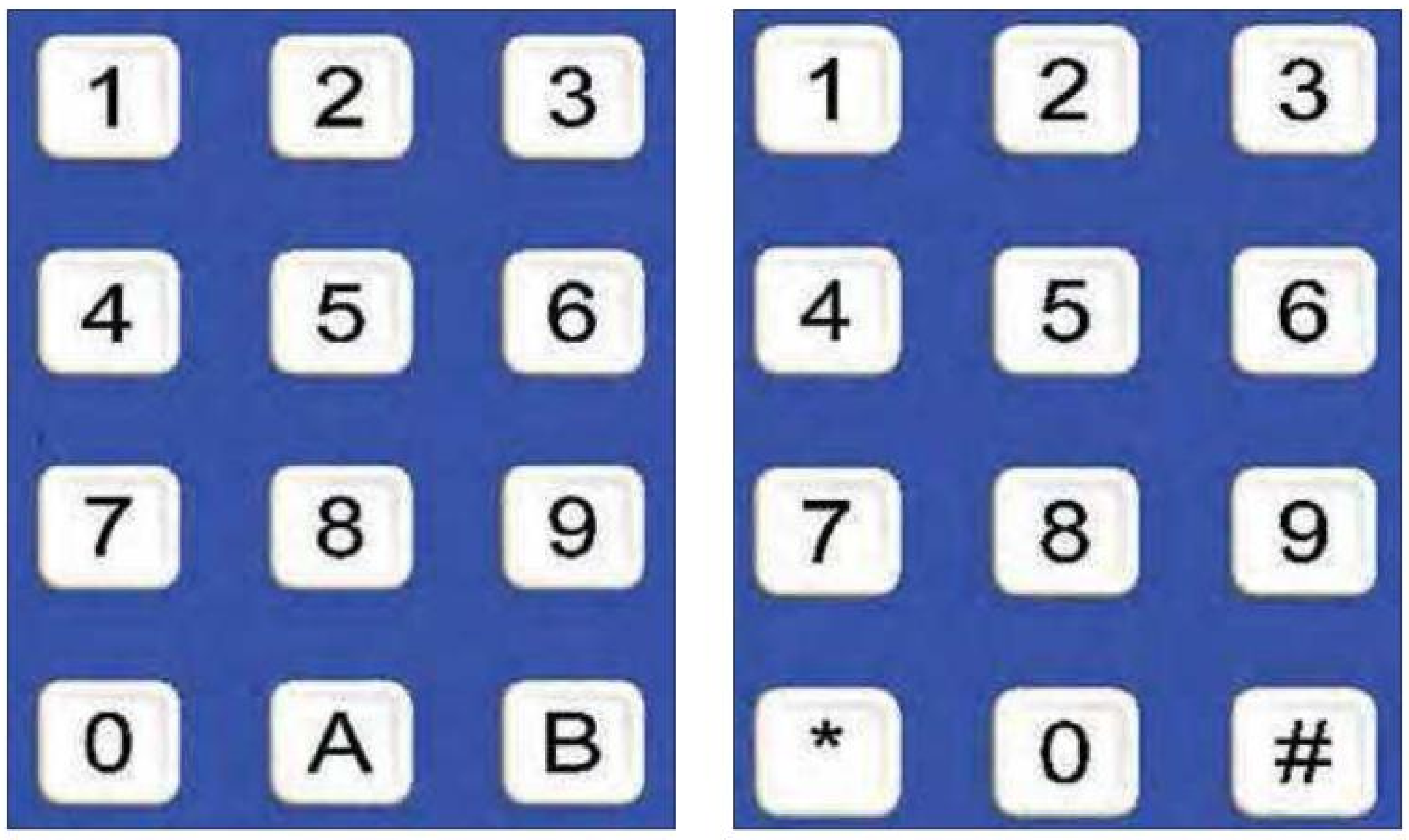


Fig.4 (left) Keypad before editing, and (right) after editing.

Digital Clock parts list

The parts you will need for the Flowcode clock project are as follow:

- Solderless breadboard
- DS1307/DS3231/DS3232 Real-time clock (RTC) module
- Keypad – 4x4 membrane type (note, only 3x4 buttons used)
- 16x2 LCD – LCD 1602 (or 2004) with HD44780 chipset (see *PE*, April 2022)
- Trimmer resistor – 10kΩ contrast adjustment for LCD
- 4x 100Ω resistors – pull-downs for RedBoard ports
- 3x 10kΩ resistors – in series with keypad, protects RedBoard
- Jumper wires.

Adding Flowcode components

To start, load Flowcode and set the target as the RedBoard (see *PE*, January 2022). Next, the components are added from the Components ribbon, either via search or by selecting a component category. To add components using search, use the following terms in quotes and then select the item listed on the right:

Item	Term	Choice
Keypad	‘key’	Keypad (Generic)
LCD	‘lcd’	LCD (Generic, 16x2)
Real-time clock	‘rtc’	Real Time Clock (Internal, DS1307, DS3231, DS3232)

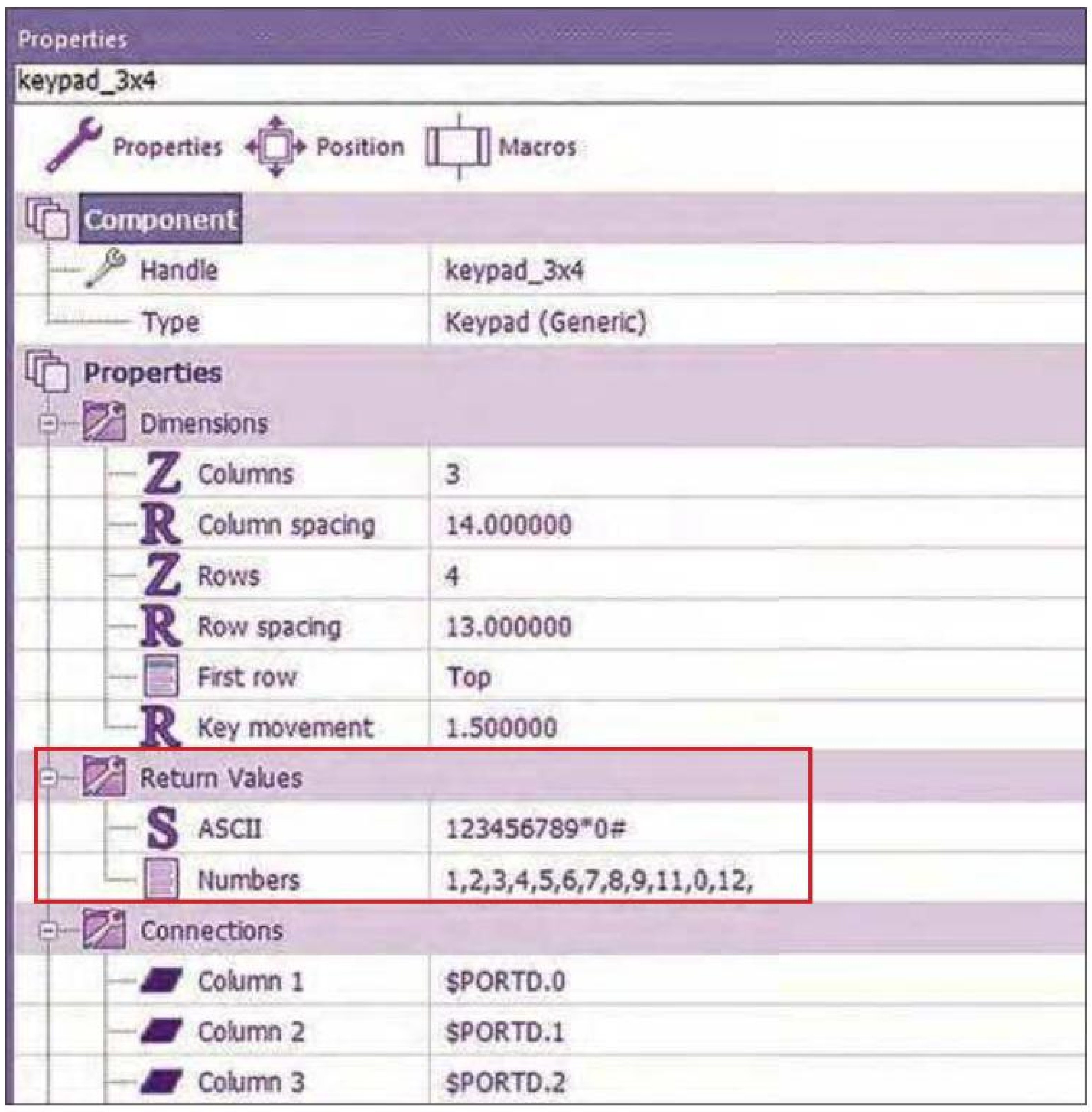
After all the components have been added to the 2D panel, Project Explorer should look like Fig.3 (with the component functions minimised). Now look at the keypad on the 2D panel – it will look like Fig.4 (left). So why only a 3x4 device when I’ve specified 4x4? The reason is that this Flowcode keypad component was originally designed just for a 3x4 device. However, it has now been updated to cover both 3x4 and 4x4 versions. It also works with both decimal and hex keypad varieties. We have a 4x4 keypad as it offers greater flexibility for future project expansion, but initially we will only use it as a 3x4 device, as explained below.

Setting properties

Next, we need to set some component properties in our keypad and RTC. We want to change the keypad so that its Flowcode image matches the three left-hand columns of our actual keypad. This means changing the bottom row so that left to right, it will read `* 0 #` instead of `0 A B`.

Referring to Fig.5, we do this by changing the properties of the keypad component. Open the properties window and edit the Return Values. In the ASCII box, change:
`1234567890ABCDEF` to:
`123456789*0#` (ie, replace `0ABCDEF` with `*0#`)

In the Numbers box, change:
`1,2,3,4,5,6,7,8,9,11,10,12,13,14,15,16` to:
`1,2,3,4,5,6,7,8,9,11,0,12` (ie, delete `,13,14,15,16`)



Component	
Handle	keypad_3x4
Type	Keypad (Generic)
Properties	
Dimensions	
Columns	3
Column spacing	14.000000
Rows	4
Row spacing	13.000000
First row	Top
Key movement	1.500000
Return Values	
ASCII	123456789*0#
Numbers	1,2,3,4,5,6,7,8,9,11,0,12,
Connections	
Column 1	$PORTD.0
Column 2	$PORTD.1
Column 3	$PORTD.2

Fig.5. Editing the keypad’s properties

If you don’t make this change the keypad will not work as expected with the program. After the change has been implemented, the keypad will look like Fig.4 (right).

When it comes to wiring the keypad, its cable connector terminals have the row (R) and column (C) connections from left to right shoen here: R1, R2, R3, R4, C1, C2, C3 and C4. (This is the usual arrangement, but if possible, do check with a datasheet or vendor specification.)

Now we need to set one RTC property. Select the properties of the RTC and make sure `Simulate Comms` is set to `No`.

Programming foundations

Next, we are going to lay some foundations for the Flowcode program which we will build next month. This will be a more involved program than the ones we have looked at so far, and we need to expand our repertoire of Flowcode tools to build a useable digital clock. We will expand some of the concepts used in the *Traffic Lights* (*PE*, February 2022) and *LCD Temperature Monitor* (*PE*, April 2022) projects, plus introduce some brand new ideas.

Variable and operators

Two of the most important concepts in programming are the ideas of ‘variables’ and ‘operators’. We’ve already met some kinds of variables in our earlier programs, but now would be a good time to clarify some of their properties. Also, we will make use of operators in the clock program, so we will provide an overview of those too.

Variables

A variable is a value that can change, depending on conditions, a calculation or based on information passed to the program. It can represent the value of something physical – say temperature – or it can be something more conceptual, say an interest rate. Such variables have a numerical value and there is a choice of numerical formats (floating point, integer, byte). Alternatively, a variable can indicate a system’s logical status (eg, True/False, yes/no, on/off, 1/0). Another important category of variable is a particular ordering of characters, typically called a ‘string’, or less formally, ‘text’.

Global and local variables

Whatever the variable type or whatever it represents, variables can be classed as either ‘global’ or ‘local’. If it is global,

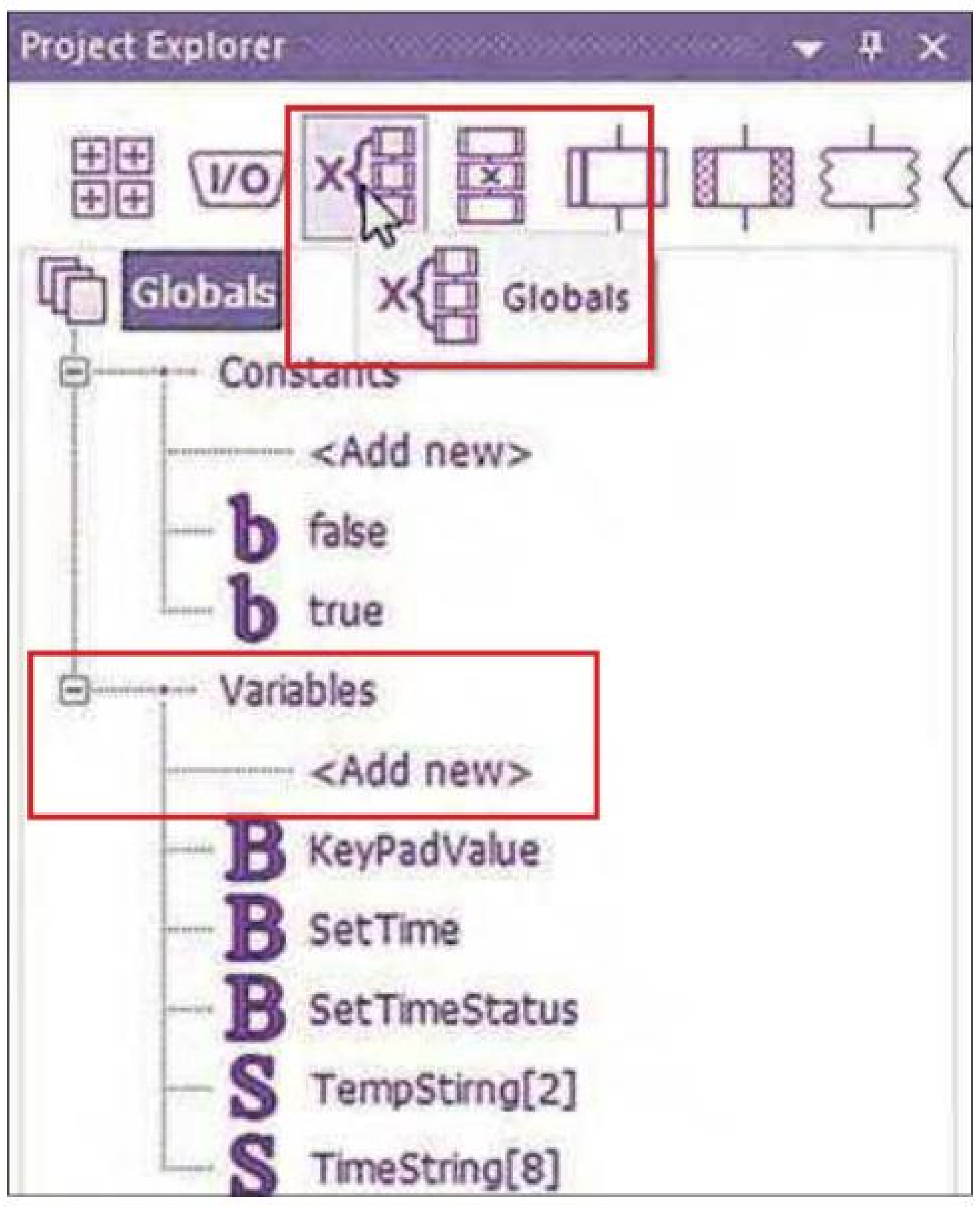


Fig.6. Adding a new global variable in Project Explorer.

then the variable is available for use in in any User Macro within the whole program. On the other hand, if it is a local variable then it will only be available within the User Macro in which it was created. Furthermore, once the User Macro has finished (ie, the program has moved on to a different User Macro) the local variable will be erased, and it is not available for other User Macros. If the User Macro is accessed again then the local variable is created afresh, starting with whatever initial value the User Macro assigns.

Top programming tip: it is good programming practice to use local variables whenever you can. Global variables use more memory resources and local variables encourage better programming and more reliable programs.

You can spot a local variable because it must always start with full stop / period; eg, `.MyLocalVariable`

You add variables from the Project Explorer (as shown in Fig.19 and Fig.20 in the *PE*, February 2022 Flowcode article). Fig.6 below shows the result of clicking on the 'Globals' icon. Next, click on <Add new> under Variables and then enter your variable data in the resulting variable window.

Local variables are added in a similar way by clicking on the icon to the right of 'Globals'in the Project Explorer. Note that when creating a local variable you *must* be in the User Macro where the local variable is to reside.

String variables

We mentioned numerical and logical (True/False, on/off, 1/0…) variables above, and since we covered these in previous articles (see: *PE*, February 2022) we won't expand on these here. However, although we introduced string variables in the *LCD Temperature Monitor* (*PE*, April 2022), we didn't go into a great deal of detail, so let's a take a closer look.

String variables are used for storing and comparing text. (In fact, a short piece of text is called a 'string'.) When defining them, the string must start and finish with double quotation marks. For example, suppose we want a global string variable called `MyString`, and we want it to contain the string `Hello World`, then we would type:

```
MyString = "Hello World"
```

The default size of a string variable is 20 bytes, which is 20 characters. This can be changed by entering the number of required bytes into `Array Length` in the Create A New Variable window, you then click Add Array Dimension. The square brackets at the end of the string name will be the number of bytes used.

Always bear in mind that the more bytes assigned, the more memory is used within the microcontroller, so it's best to keep the assigned string length as short as possible. (Again, see Fig.19 and Fig.20 in the *PE*, February 2022 Flowcode article.)

String conversions

Things start to get more interesting when you manipulate string variables. You might want to convert a string to a byte variable or a byte to a string variable. For example, suppose you wanted to enter the time '09' to be displayed on the LCD; entering the *numeric* value '09' as a byte will result in just 9 being stored, so only 9 will be displayed. However, if 09 is a string, then it will be stored and displayed as '09'.

There are quite a few functions that operate on strings, and they can be found by selecting the `f$` icon, top right of the calculation icon. In this project we will use two of these: `ToString$()` and `StringToInt$()`

`ToString$()` converts bytes or integers into a string, for example:

```
TempString = TempString +
ToString$ (.ReadKeypad)
```

This expression (see below for an explanation of the term 'expression') will take the number that is assigned to the local variable `.ReadKeypad`, convert it to a string and 'add' it to whatever is the current value of the string `TempString`. If `TempString` is the string `1` and `.ReadKeypad` is the number `6`, then `ToString$` converts the number `6` to the string `6` and adds it to the contents of TempString creating the string `16`. It's important to note that this new `16` is a piece of text, it is not a number. Likewise, `StringToInt$()` converts a string to an integer. Naturally, it can only convert strings written with number characters. So to converts the string `123` to the integer `123`, you would use `StringToInt$(123)`

Operators

Variables are clearly useful, but you need a variety of ways to manipulate them – just as we did with the simple string 'addition' example above. This is where operators come into the picture. An operator is a process which 'operates' on a variable or value. For example, you will recognise these basic arithmetic operators: +, –, /, * and =.

Operators are applied to 'operands' (variables and constants) and these combinations are used to create an 'expression', which can reduce multiple variables to a single value. For example, 6 + 4 = 10 is an expression that takes two operands and reduces it to one value. Likewise, you could add together two numeric variables to create a new value:

```
CostofProject = Parts + PCB
```

Also, as we saw above, you can use some operators on strings to create useful expressions, and in this case, the expression's output would also be a string.

Comparison operators

In programming, an essential class of operator make comparisons between operands (variables and constants). There are five varieties of these, and they each ask one of five questions about the relative size of the two operands, here generalised to x and y:

`x > y` is x greater than y
`x < y` is x less than y
`x >= y` is x greater than or equal to y
`x <= y` is x less than or equal to y
`x == y` is x equal y

These operators are used in decision making branches, and their outputs are the characteristic 'yes' or 'no' that you see in flowcharts.

Use == or = for comparisons?

Notice that for the equals comparator above I wrote a double-equals sign. The equals sign (=) has more than one use in Flowcode. For example, a single = is used for all assignment operations, so to set a variable to a value we use: `SetTime = 11`. You can use the single version in comparisons, but to avoid ambiguity it's best to use the double version for a comparison operator.

Logical operators

Flowcode has operators that act like the familiar logic gates ICs, producing logical `AND` and logical `OR`:

`||` Flowcode `OR`
`&&` Flowcode `AND`

The character '|' is known as the 'pipe' symbol. You can find it to the left of the key `Z` on a standard UK computer keyboard. Note that you must type two pipes or two ampersands (&) to create an `OR` operator or `AND` operator – one won't work.

Brackets

When you combine several operators and operands in one expression, it can become difficult to work out exactly what the expression is supposed to mean. A simple example from arithmetic is: $x = 2 + 3 \times 4$. There are two possible ways of looking at this. Do you multiply 3 times 4 and then add 2 to create 14; or, do you add 2 to 3 and then multiply by 4 to produce 20? Now, although there are strict rules for interpreting this kind of expression this example does highlight that ambiguity can creep into expressions and it's easy to make mistakes, which can be a nightmare to troubleshoot.

The best approach is to use brackets to effectively create sub-expressions; for example, x = (2 + 3) x 4 or x = 2 + (3 x 4), depending on what you want to calculate. It never hurts to liberally sprinkle brackets in your expressions and thereby make it clear to yourself (and anyone else who might use or edit your code) what you intend the expression to do.

You can use brackets with logical operators too – in fact they are especially useful with this type of expression. For example, here is an expression from some code which we will meet later in a User Macro called `TimeSetValidity`

```
(KeypadValue == 1 && SetTime > 23) || (KeypadValue
== 2 && SetTime > 59) || (KeypadValue == 3 &&
SetTime > 59)
```

This might look a little daunting at first, but the use of brackets makes it much easier to understand; all it is doing is asking if:

The `KeypadValue` is `1 AND` the SetTime variable is greater than `23`

`OR`

The `KeypadValue` is `2 AND` the `SetTime` variable is greater than `59`

`OR`

The `KeypadValue` is `3 AND` the `SetTime` variable is greater than `59`

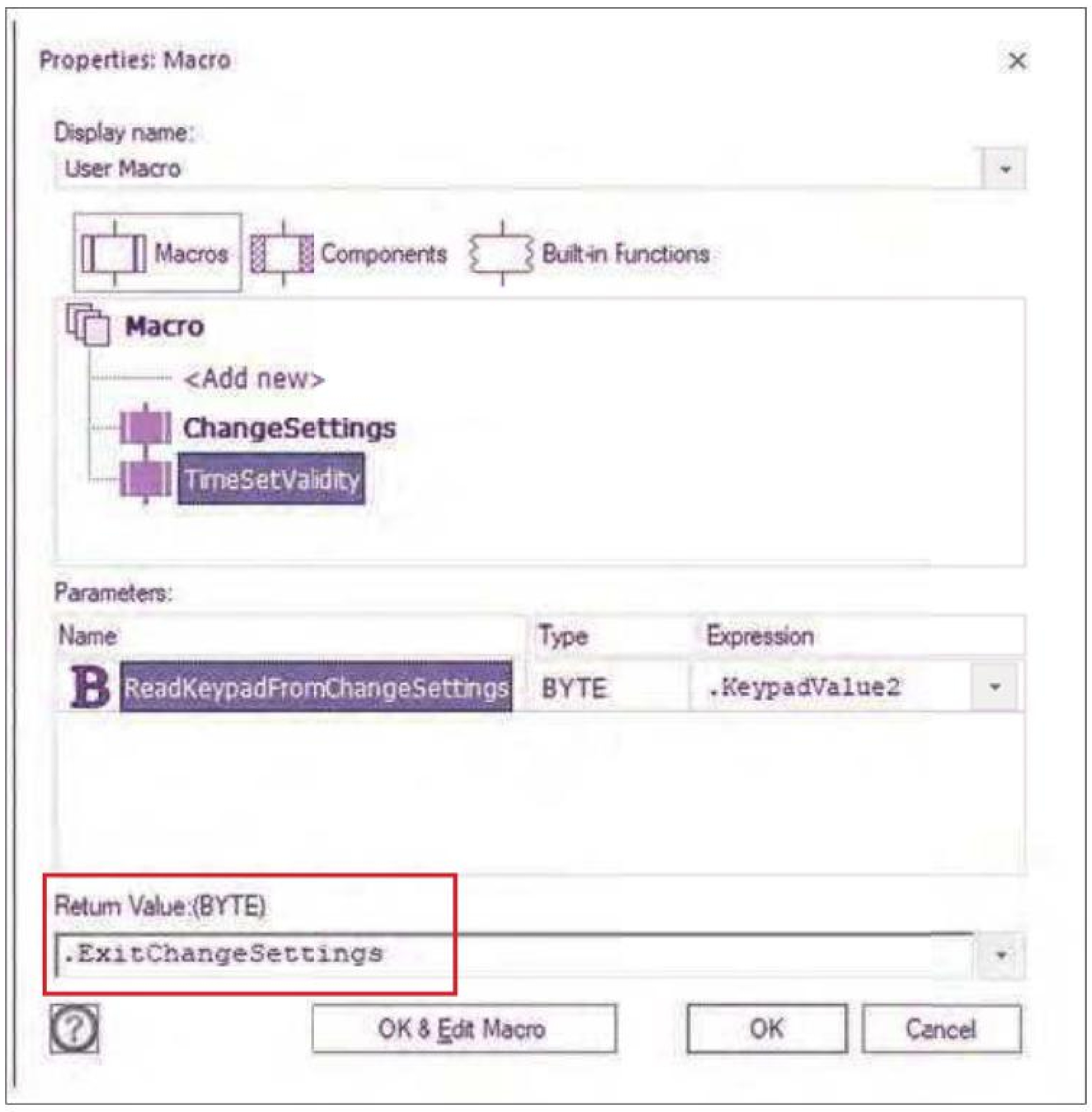
The answer to this whole expression will be 'yes' or 'no', and from there the program will branch one way or another. Try writing out the expression without brackets and you will see that it becomes much harder to understand – do you apply `AND` or `OR` first? Remember, when it comes to expressions, brackets are your friends – use them!

Call macro parameters and return values

I mentioned above that it's always better to use local variable where possible – but that a local variable is erased when the program exits the User Macro where it is used. This does of course present a problem if the value of the local variable is of potential use in a different User Macro. The way round this conundrum is to 'Return' the value.

When you create a new User Macro, if you require a value to be delivered to another User Macro then go to the Properties window and enter the local variable in the drop-down of the Return Value box (see Fig.7). Also, the value of the variable will only be passed back if it's *assigned* to the `.Return` local variable. For example, if you want the value of (for example) the `Hours` variable to be available, then the last expression within a calculation icon must be:

```
.Return = Hours
```



Display name: User Macro

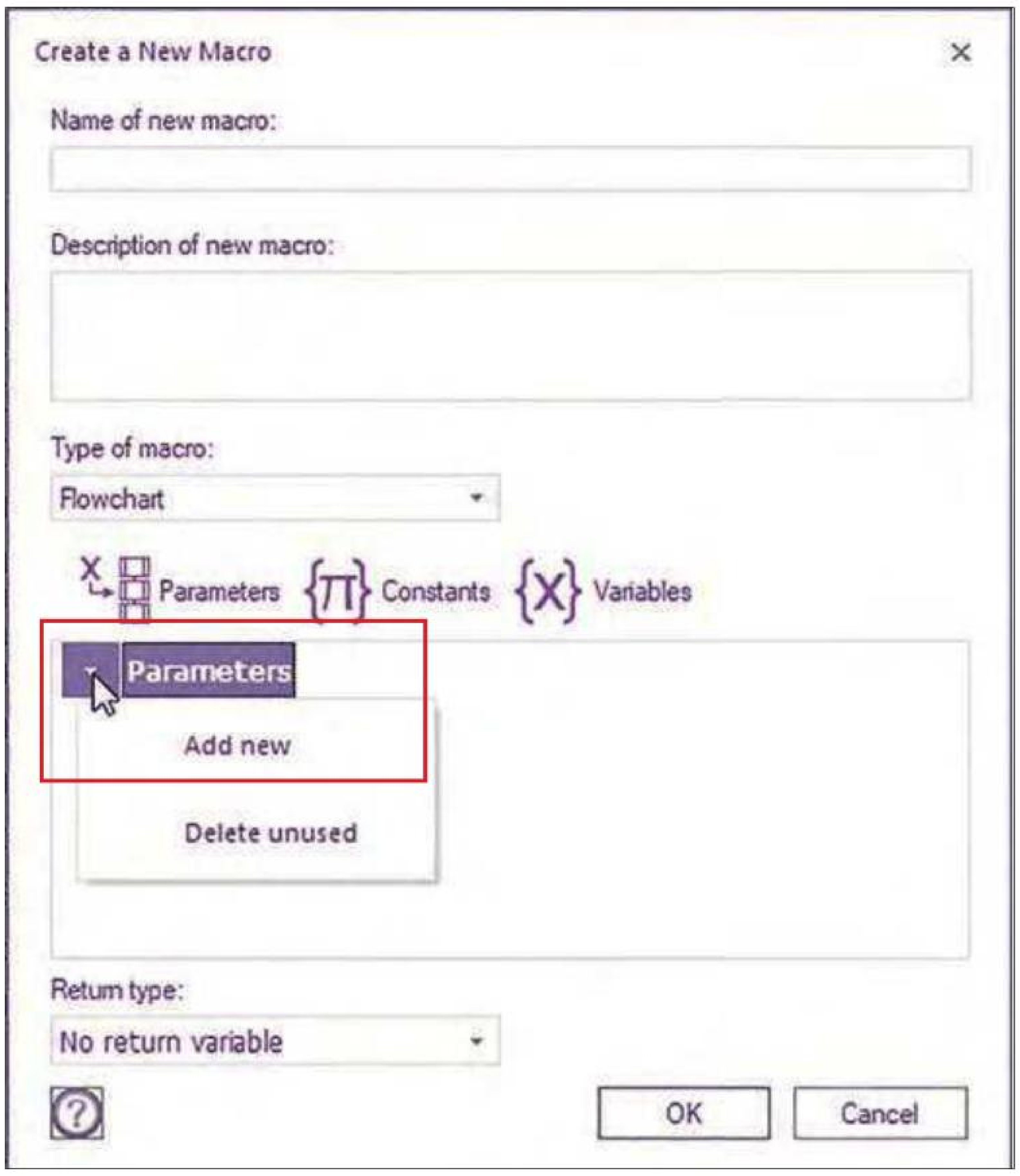
Name	Type	Expression
ReadKeypadFromChangeSettings	BYTE	.KeypadValue2

Return Value:(BYTE) .ExitChangeSettings

Fig.7. Setting up the .Return facility of a User Macro

The local variable is only 'Returned' on exit from its User Macro and only one local variable can be returned. Any kind of variable (float, string, byte, integer) or just a number can be returned.

User Macros often also need to receive parameters – this is called 'passing' parameters and allows a User Macro to be given values from other sources. You can pass as many different parameter as you like. These parameters are set up in the Parameters box of the same User Macro Properties window as the Return item (Fig.8)



Type of macro: Flowchart

Return type: No return variable

Fig.8. Adding a parameter

Program overview

We've covered a lot of useful theoretical material. Now, we return to the project and discuss program operation. Fig.9 shows an overview of the *Digital Clock's* flowchart.

1. At power up, the program commences with Start.
2. The microcontroller initialises the RTC and LCD.
3. The microcontroller retrieves Hours, Minutes and Seconds data from the LCD and sends it for display on the LCD.
4. The microcontroller checks the keypad value and determines if a key has been pressed.
5. If not, it waits for 100ms and then returns to item 3 and repeats.
6. If a key press has been detected then the microcontroller checks if key 1, 2 or 3 was pressed via the next three decision boxes. If not, it returns to item 3. Note: at this point in the flowchart the program is designed to only move on if 1, 2 or 3 is pressed. All other keys will be seen as an error and ignored.
7. If 1, 2 or 3 has been pressed the program passes this information to the Run set time routine. A 1 means Hours are to be set; a 2 means Minutes; and a 3 indicates Seconds.
8. The Run set time routine waits for the Hours, Minutes or Seconds data, plus a terminating # key press. If a # is not detected, then the program returns to the start of the Run set time routine.
9. If you enter the wrong digit you can exit and re-enter the Run set time toutine by pressing the the * key.
10. When the # key is detected a time validation is performed. This is to check if a nonsense value has been entered, for example 83 Seconds. If a false value has been entered then the digits are cleared and the program returns to the start of the Run set time routine.
11. If valid time data has been entered then these are written to the RTC and the program returns to item 3.

The program continues to loop round from item 3 to 11 until the circuit is powered down.

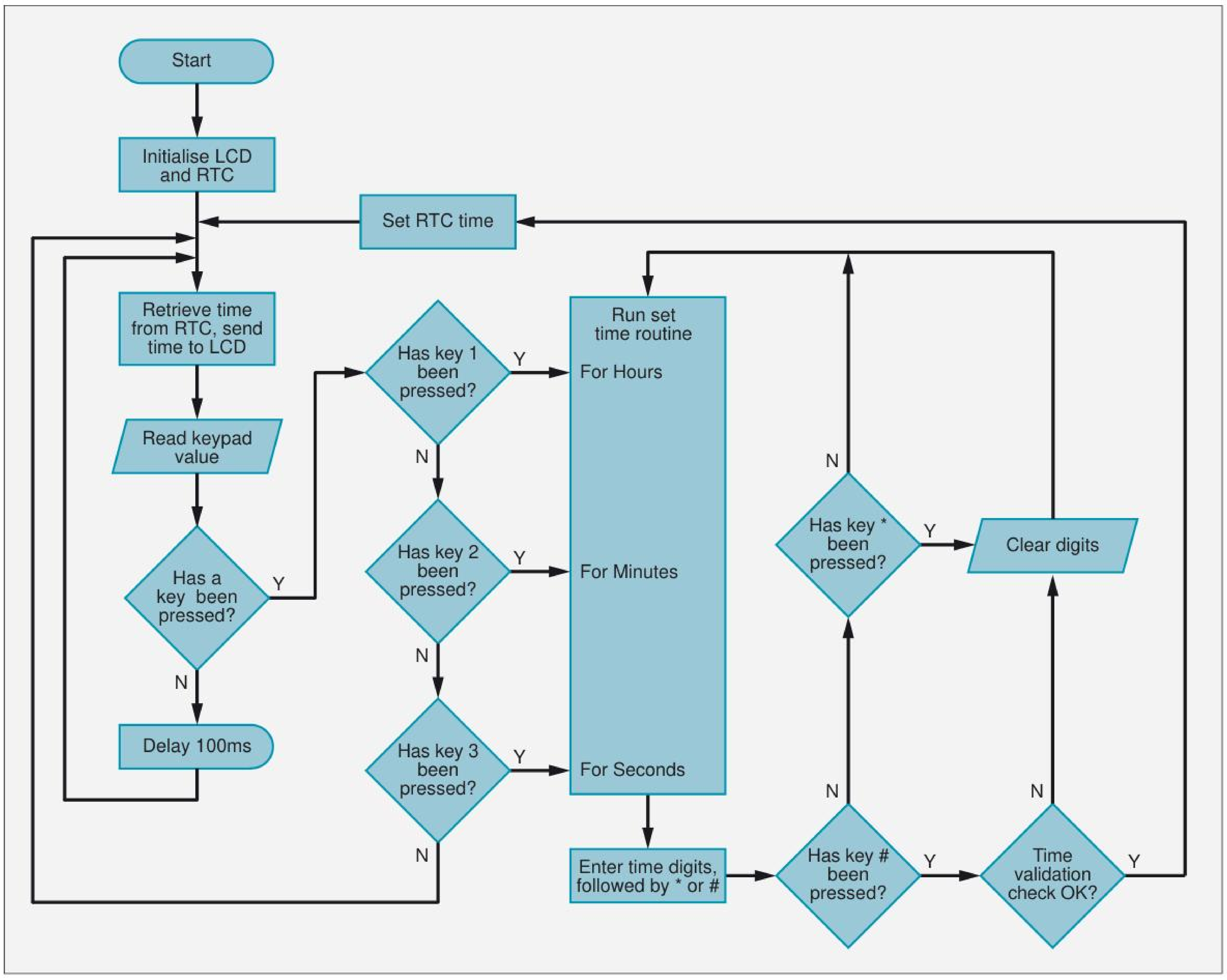


Fig.9. Flowchart of the Flowcode *Digital Clock* program.

Next month

That's all for this month except to say that the *Digital Clock* Flowcode program which we will cover in detail next month is available for download from the July 2022 page of the *PE* website. Do have a look at it now before we dive into all its details in the August issue!

Martin Whitlock is an Applications Engineer at Matrix TSL – the company which is behind Flowcode.

Try Flowcode for *free!*

We hope you found this article interesting. If you'd like to try Flowcode for free then just go to **https://flowcode.co.uk/download/** and download the code. You'll get a 30-day free trial of the full version – but that's not all. Even after the 30 days are up your copy of Flowcode will continue to work, but at a reduced level with a limit on the size of program you can run and access to a more basic set of parts. However, for beginners it is still an ideal platform with which you can build and run programs, on for example, the Arduino Uno/RedBoard or a PIC 16F88 that we are using in this project.

Only when you are sure that you want to use Flowcode do you need to buy *inexpensive* access to say a Raspberry Pi or Bluetooth module. (See: **https://flowcode.co.uk/buy/process/** for all the modules available and what they contain.) What's more, as soon as you buy *any* module, the restrictions on the size of your code are removed.

If you get stuck with anything relating to Flowcode use (installation, software, creating flowcharts, compiling to hardware, hardware not working…) then there are forums set up to help you: **https://www.flowcode.co.uk/forums**

PE discount!

One more thing – Flowcode is deliberately designed to be inexpensive, but *PE* readers can get a further 20% discount when they use the code **PE20** at checkout.

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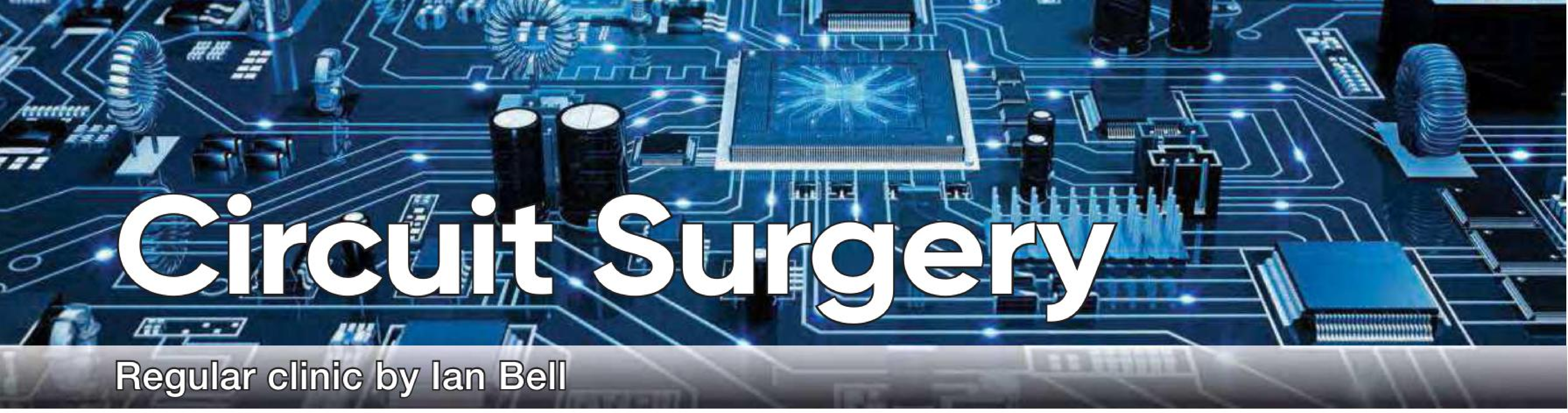


Circuit Surgery

Regular clinic by Ian Bell

Distortion and distortion circuits – Part 2

Last month, we started looking at distortion, which is the changing of the shape of waveforms due to nonlinearities in circuits such as amplifiers. This was inspired by a couple of *PE* projects by John Clarke on sound processing effects for musicians, including the recent *Digital FX* system and the *Nutube Guitar Overdrive and Distortion Pedal* from March 2021. Although deliberate distortion is used creatively by musicians, distortion is often an unwanted characteristic and circuit designers make significant efforts to minimise it. The amount of unwanted distortion is often measured using Total Harmonic Distortion (THD), particularly in audio applications.

Distortion and Spectra

In *Part 1* last month we covered the basic principles of distortion, including the importance of the spectrum of a signal in understanding distortion and the mathematics behind THD. To recap briefly, a spectrum is a plot of signal strength (amplitude or power) against frequency, which therefore shows all the frequencies present in a signal (within the range plotted).

Any periodic waveform can be formed by adding together a set of sinewaves of various frequencies and different amplitudes. This 'sum of sinewaves' is known as a Fourier series. The spectrum plot of a periodic signal therefore comprises a set of peaks at various frequencies, and the sinewave itself is the only signal that has just one peak in its spectrum.

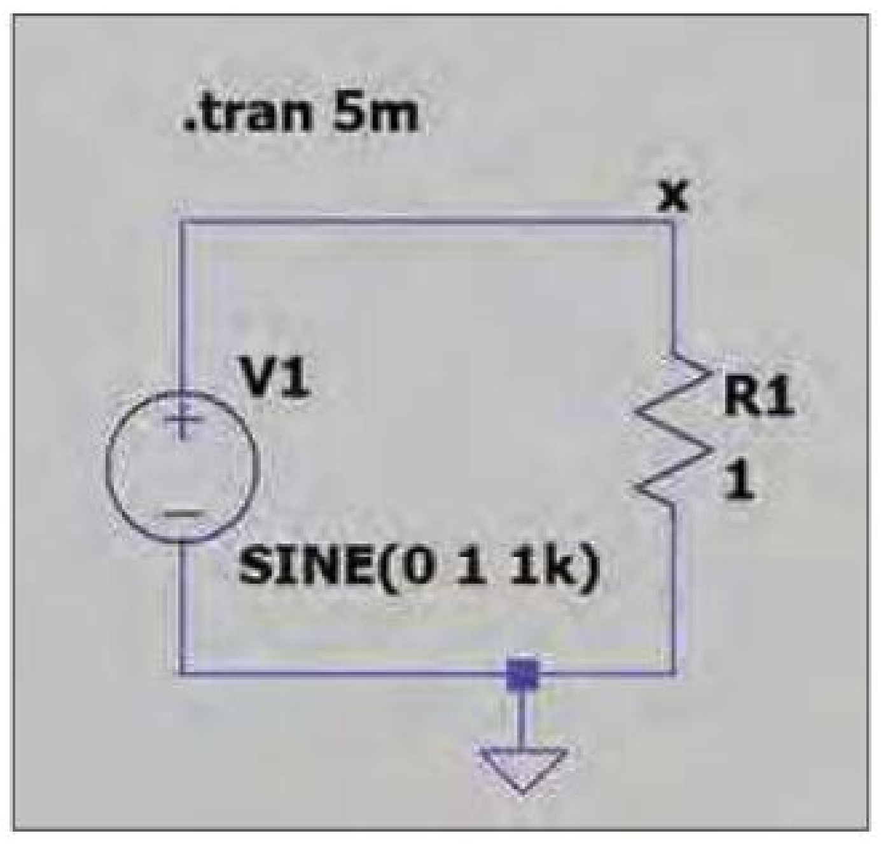
When a sinewave is input to an ideal amplifier the output spectrum has the same form as the input – a single peak – but with the amplitude changed by the amplifier's gain. For a non-ideal (non-linear) amplifier the output will contain frequencies which were not present in the input. The presence of the additional frequencies changes the shape of the waveform. Change of wave shape is an intuitive idea of what distortion does, but is not sufficient to define distortion. A change of waveform shape will also occur for non-sinusoidal inputs to perfect linear filters (eg, 'rounding off' of a square wave). This is because the relative amplitude of the spectral peaks is changed – but the output does not contain additional frequencies.

Simulation files

Most, but not every month, LTSpice is used to support descriptions and analysis in *Circuit Surgery*.
The examples and files are available for download from the *PE* website.

The theory we discussed last month shows that for a sinewave input the additional output frequencies due to distortion will be at multiples of the input frequencies, that is, harmonics of the input. If we find the ratio between the power of the output signal at the input frequency and the power of the sum of all the additional frequencies due to distortion, then we get a useful indication of how much distortion a circuit produces. Because we are adding up all the contributions of the harmonics, this measure is called 'Total Harmonic Distortion'. If the input signal contains multiple non-harmonically related frequencies the effects of distortion are more complex, containing sum, difference and other combination frequencies – this is called 'intermodulation distortion'.

Fig.1. A very simple circuit for investigating spectra in LTspice.



In the context of a single music note, the input will in most cases already contain harmonics – these define the timbre of the note (musical quality other than pitch loudness), thus distortion will change the relative harmonic content and hence the timbre, typically producing a 'fuzzier', 'grittier' or 'harsher' sound.

Using LTspice

Last month, we illustrated parts of the article with LTspice simulations, including plots of signal spectra. However, we did not explain how these were obtained, so this month we will look at how to plot signal spectra and calculate THD with LTspice. THD can be calculated manually from a spectral plot, but LTspice has a

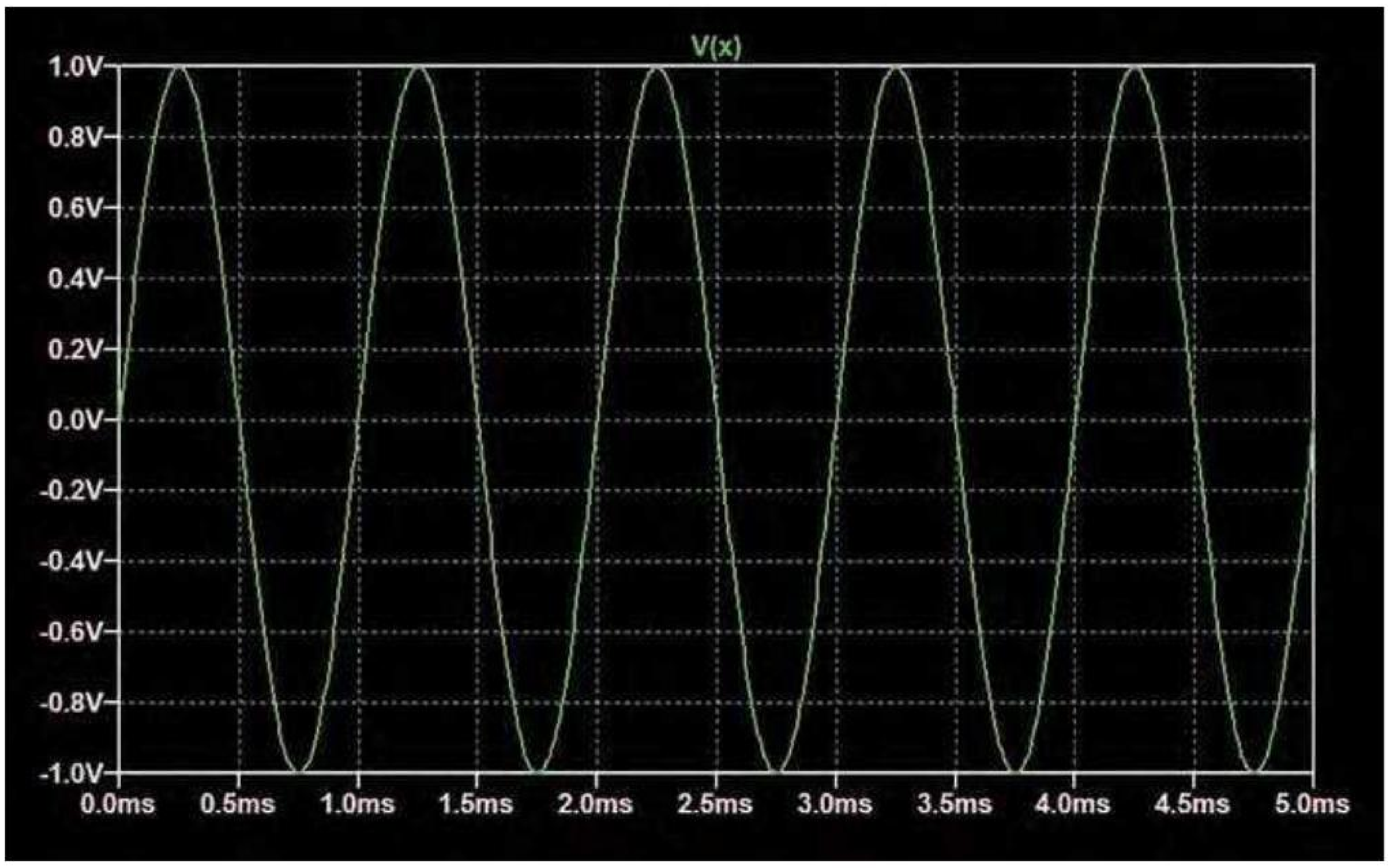
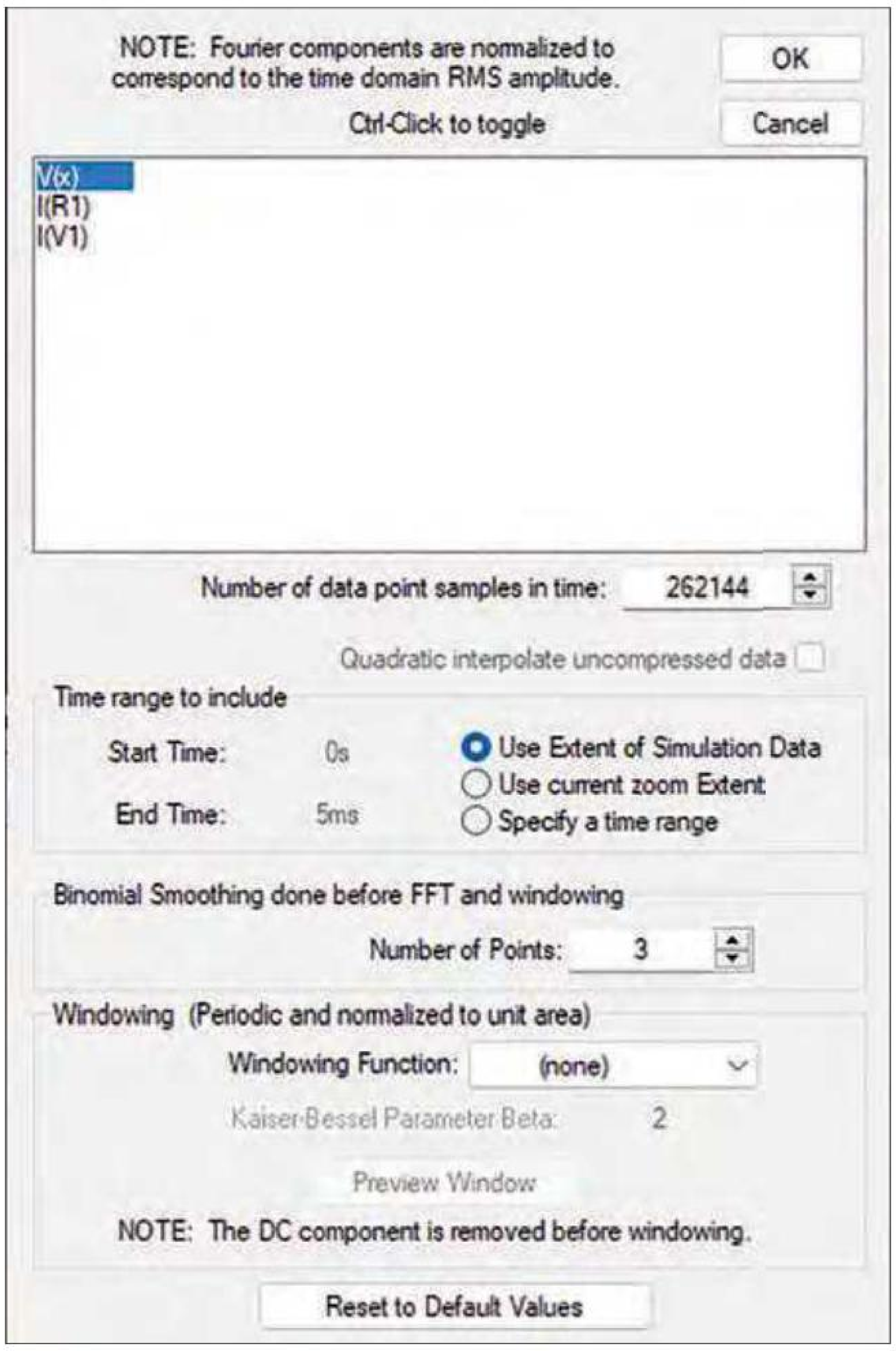


Fig.2. The waveform of `V(x)` from the transient analysis of Fig.1.



NOTE: Fourier components are normalized to correspond to the time domain RMS amplitude.

Ctrl-Click to toggle

V(x)
I(R1)
I(V1)

Number of data point samples in time: 262144

Quadratic interpolate uncompressed data ☐

Time range to include

Start Time: 0s

End Time: 5ms

● Use Extent of Simulation Data
○ Use current zoom Extent
○ Specify a time range

Binomial Smoothing done before FFT and windowing

Number of Points: 3

Windowing (Periodic and normalized to unit area)

Windowing Function: (none)

Kaiser-Bessel Parameter Beta: 2

NOTE: The DC component is removed before windowing.

Fig.3. The FFT dialog in LTspice.

command for calculating it automatically. This does not mean that the spectral plots are not useful – they provide a visual insight into the harmonic content of a distorted waveform. For example, musicians often discuss the relative merits of distortion dominated by odd or even harmonics and relative levels of higher and lower order harmonics in terms of quality of sound. The spectrum plot allows a quick assessment of such properties of a signal. Next month, we will look at analogue circuits used to create distortion for musical effects.

The circuit in Fig.1 is the minimum needed to get LTspice to display a spectrum. To obtain a waveform to analyse with the FFT we need to run a transient simulation; the figure shows that a 5ms transient analysis has been set up. The resulting waveform is shown in Fig.2. 'FFT' refers to the 'Fast Fourier Transform', which is the mathematical algorithm used to calculate a spectrum from a waveform. The fundamental mathematics is the Discrete Fourier Transform (DFT) – 'discrete,' because the waveform data is a set of sample points, not a continuous mathematical function. The FFT is an efficient computer implementation of the DFT.

FFT plot

To see the spectrum for the waveform, right click on the waveform and select 'View' from the pop-up and then 'FFT' from the submenu. The dialog shown in Fig.3 will appear. Make sure the signal of interest, in this case `V(x)`, is selected and click OK. This will display a spectrum similar to the one in Fig.4 – note that the frequency range plotted in Fig.4 has been changed from the default to focus on the lower frequencies closer to the input frequency. To change the axis range right-click on axis numbers and enter the new range values in the dialog.

The expected spectrum for a pure 1kHz sinewave is simply a single very sharp peak at 1kHz. The spectrum in Fig.4 has a very wide peak and plenty of content at other frequencies. Fortunately, there are several things we can do to obtain a more convincing spectrum.

The spectrum in Fig.4 is plotted in decibels. The largest peaks, other than the expected one at 1kHz, are about 65dB below the 1kHz peak, this is about 2000-times smaller ($10^{-65/20} = 5.6\times10^{-4}$). This may seem small, but remember the spectrum should be zero at all frequencies except 1kHz. LTspice spectral plots will always have some content where ideally the value is zero due to the limitations in the accuracy of the calculations, but we need to make sure the errors are acceptable. In this case, we would expect much smaller errors given that we have an ideal sinewave and perfect (linear) resistor.

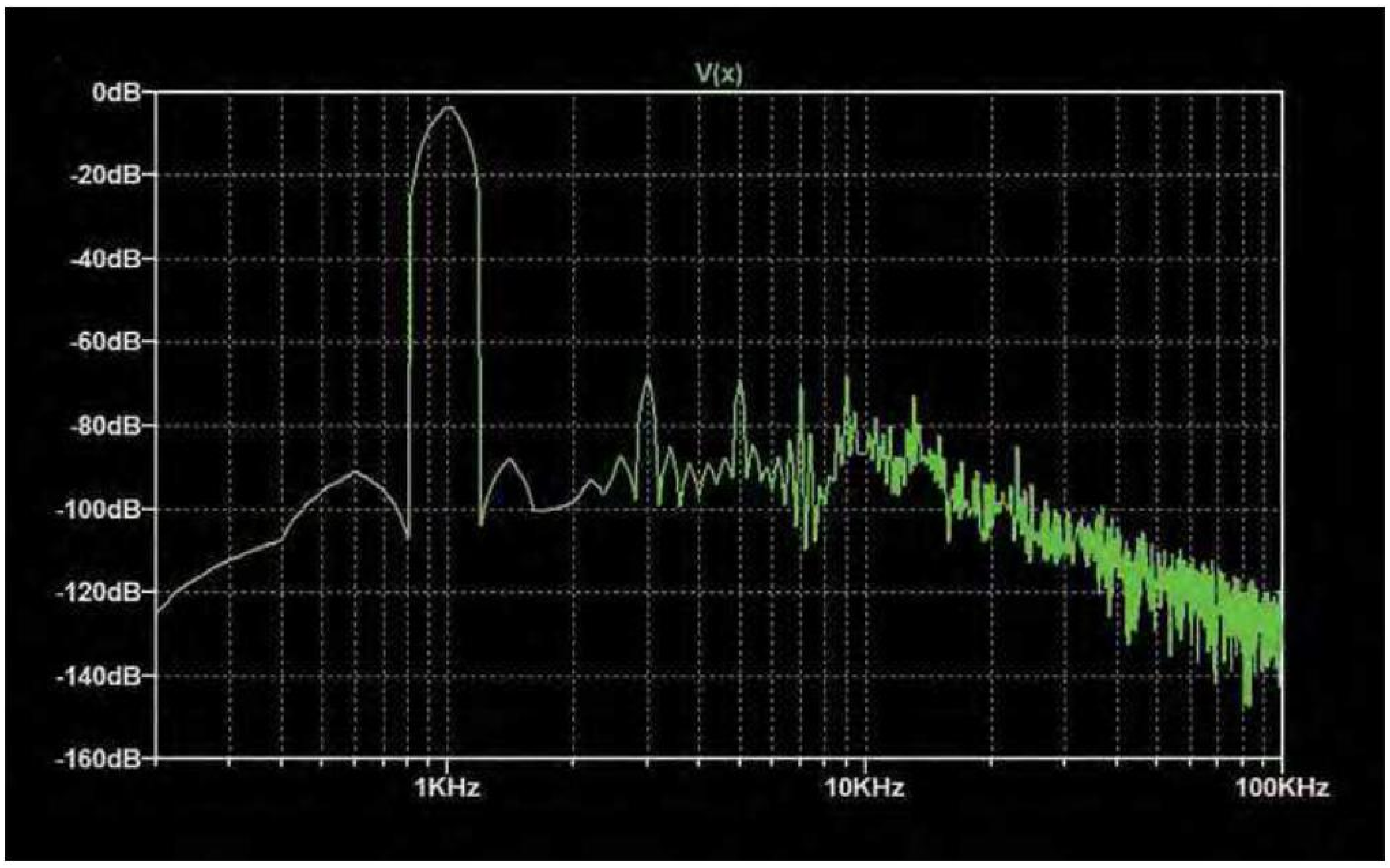


Fig.4. The initial spectrum does not look very convincing.

Compression

One problem with this initial simulation is due to the waveform data compression that LTspice employs. This is often useful because a compressed waveform file can be 50-times smaller than an un-compressed one. However, the compression is lossy, which means that information is lost during compression. Although it usually does not detract from the look of a waveform plot, this loss may degrade the quality of a spectrum calculated from the waveform data, so when you intend to analyse spectral data, compression should be turned off.

You can turn off compression using Control Panel from the Tools menu: go to the Compression tab and set the Window Size (No. of Points): value to zero. However, this setting is not remembered between program invocations, so it is better to put the command on the schematic. To do this, click on the schematic window and then on the `.op` (SPICE Directive) button on the menu bar. Enter the following text into the dialog

```
.option plotwinsize=0
```

Next, click on the schematic to add the command. Close the spectrum window and then run the simulation again (this is necessary to generate the uncompressed waveform data). Then display the spectrum again – see Fig.5.

Noise floor

For real circuits, there is always random noise present, and in measurements of signal spectra this will produce results similar to the relatively flat part of the spectrum away from the peak in Fig.5. Pure random noise over an infinite time has a perfectly flat spectrum (no peaks) at all frequencies, but with real measurements there will be variations,

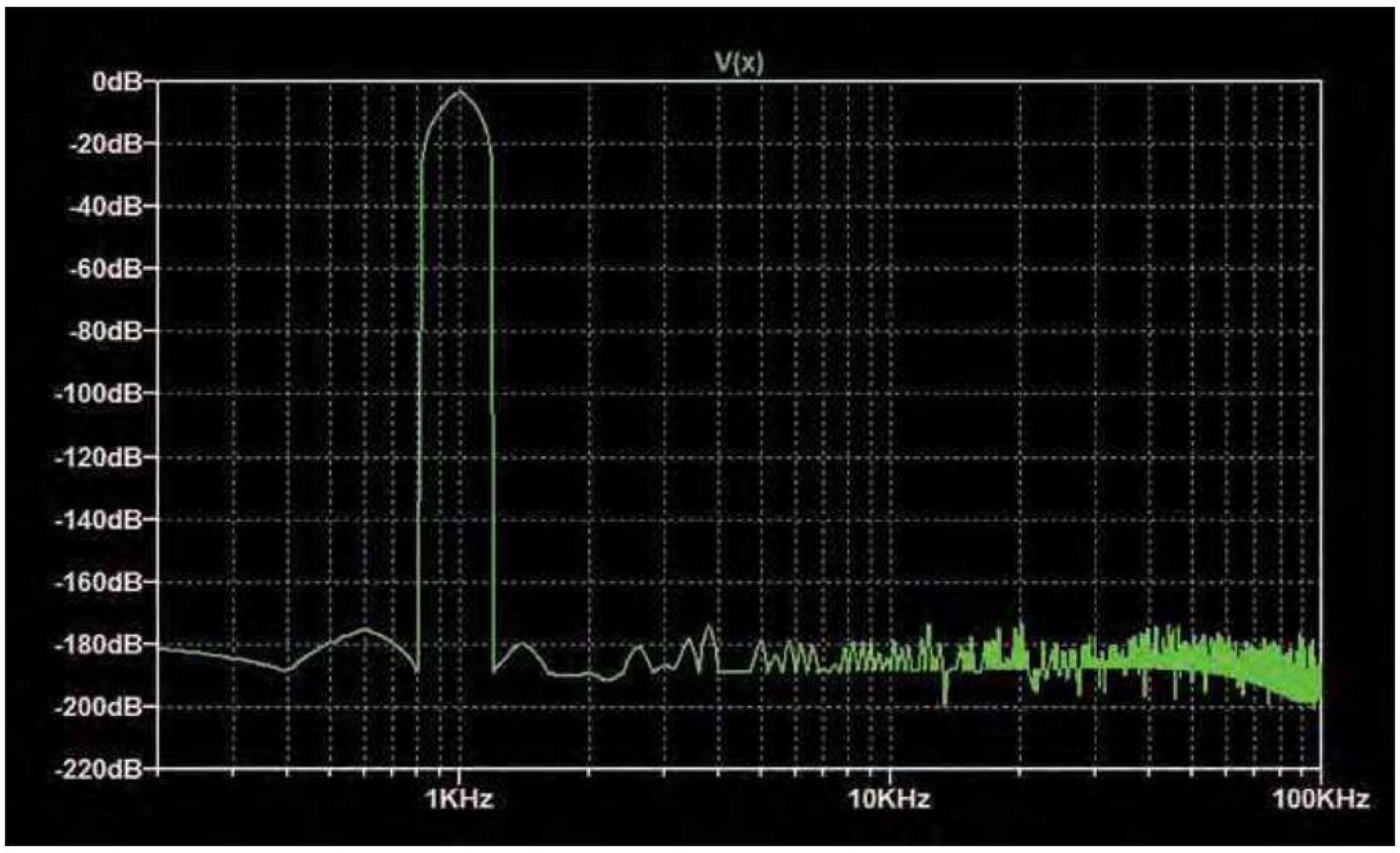


Fig.5. Avoiding data compression greatly reduces noise in the spectrum

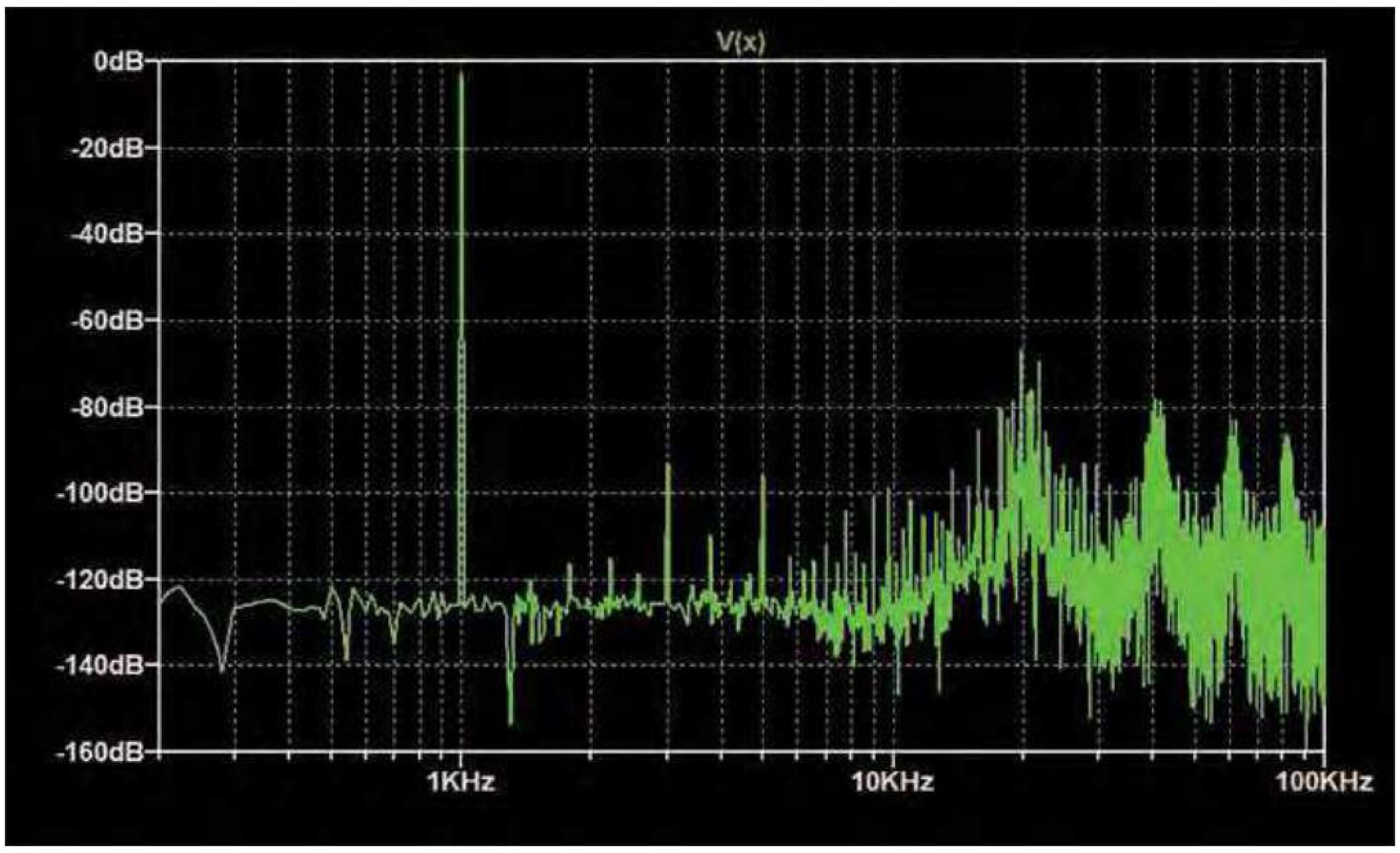


Fig.6. Using a longer simulation (more cycles) gives a narrower peak, but this attempt has more noise due to lack of simulation accuracy.

as in Fig.5. The general level of the flattish part of the spectrum between the signal peaks is called the noise floor. In simulations, like the example here, there is no random noise in the signal, but numerical errors in the simulation produce a noise floor in the spectrum.

The decibel scale appears to exaggerate the noise level if you are not used to reading decibel-scaled graphs. In Fig.5 the noise floor is around 160dB below the peak, this corresponds to a voltage 300 million times smaller than the peak. This is much smaller than the noise floor in typical real circuits.

We now have a clean spectrum, but the peak is still much wider than expected. This is due to not having enough good waveform data for the FFT to use. One thing we can do is to run the simulation for longer, so that more waveforms cycles are included. To do this use Edit Simulation Cmd from the Simulate menu and change the Stop Time to `50m`. Run the simulation again and you will see about 50 cycles. The spectrum should now look like Fig.6 – the frequency range has been changed to match the previous plots.

Accuracy

The peak at 1kHz is now much narrower, but the noise floor is worse again. This is again due to lack of accuracy in the simulation. This time it is not data compression, but the number of data points at which the simulator has calculated the waveform that is the problem. The data points used by the FFT are not at the same points in time as the points on the waveform calculated by the simulator. This is simply because they work in different ways.

The FFT uses regularly spaced samples, whereas the simulator calculates the waveform at the 'next time step', and this length of time can vary depending on how the simulator's calculations perform. If there is not a simulator waveform data point at the time required by the FFT, the FFT has to interpolate the required value using the nearest data points, which may lead to errors. However, we can force the simulator to use a certain minimum time step, so that more waveform data points are calculated during the simulation, providing better data for the FFT.

To reduce the time step, again use Edit Simulation Cmd, this time entering `10n` in the Minimum Timestep box. Leave the Stop Time at `50m`. This will force the simulator to calculate waveform data points at least every 10ns (nanoseconds). Run the simulation again – you will find it takes longer. View the spectrum again; it should look like Fig.7. We now have a sharp peak and a noise floor well below the peak. The spectrum is much closer to that of an ideal sinewave than our initial attempt.

Another way to improve accuracy is to set another option:

```
.options numdgt=7
```

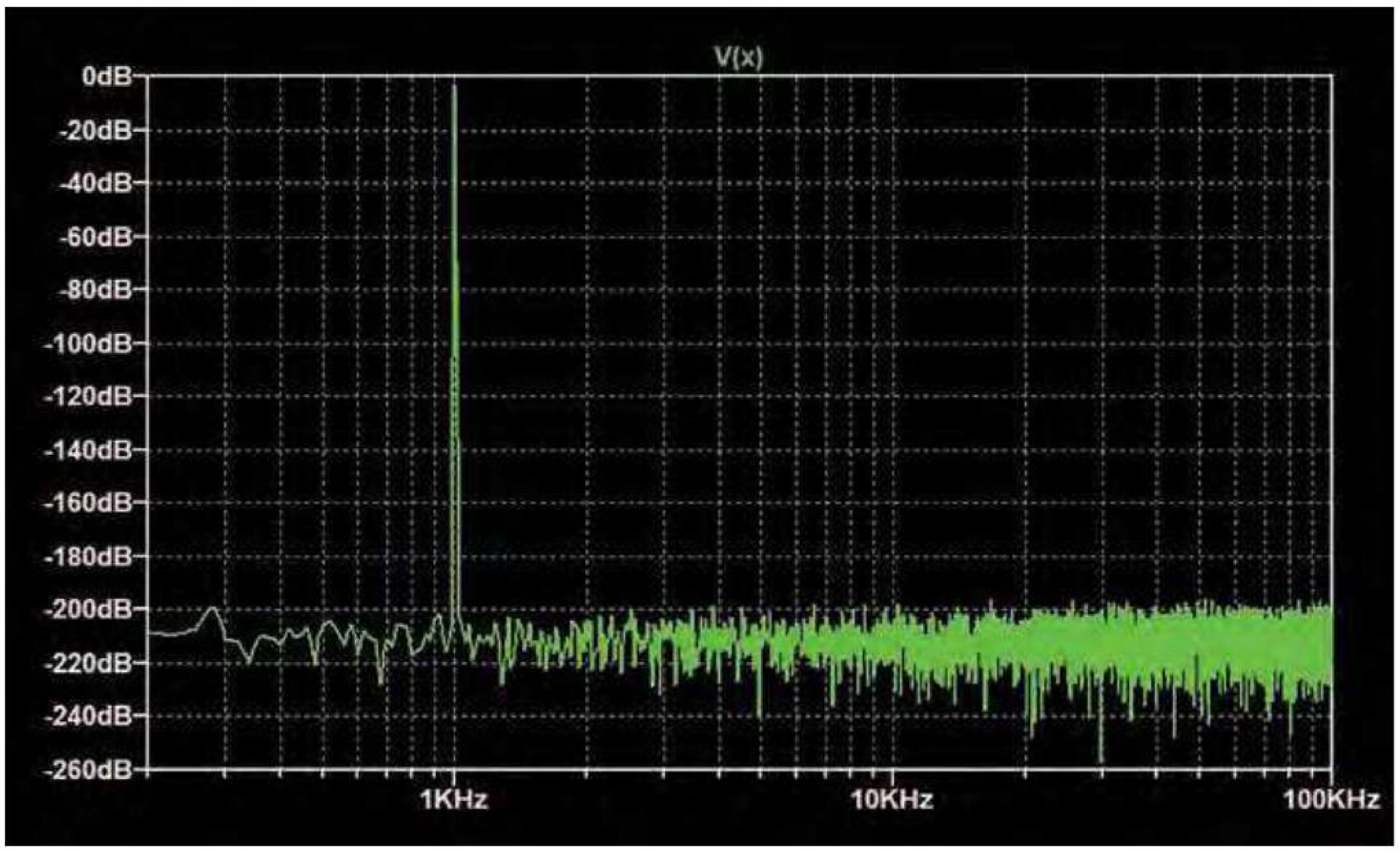


Fig.7. Improving simulation accuracy (at the expense of run time) gives a spectrum with a much better noise floor.

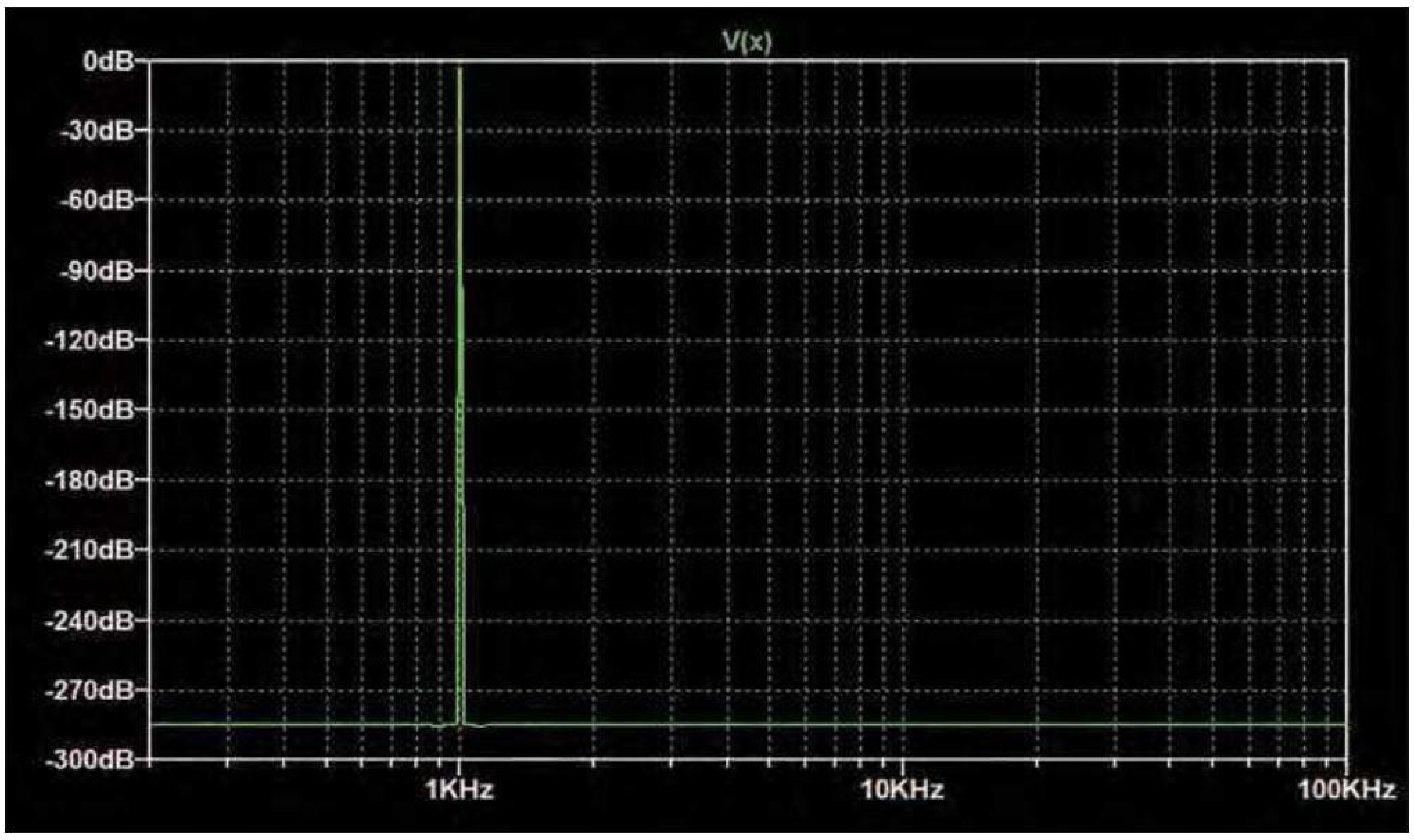
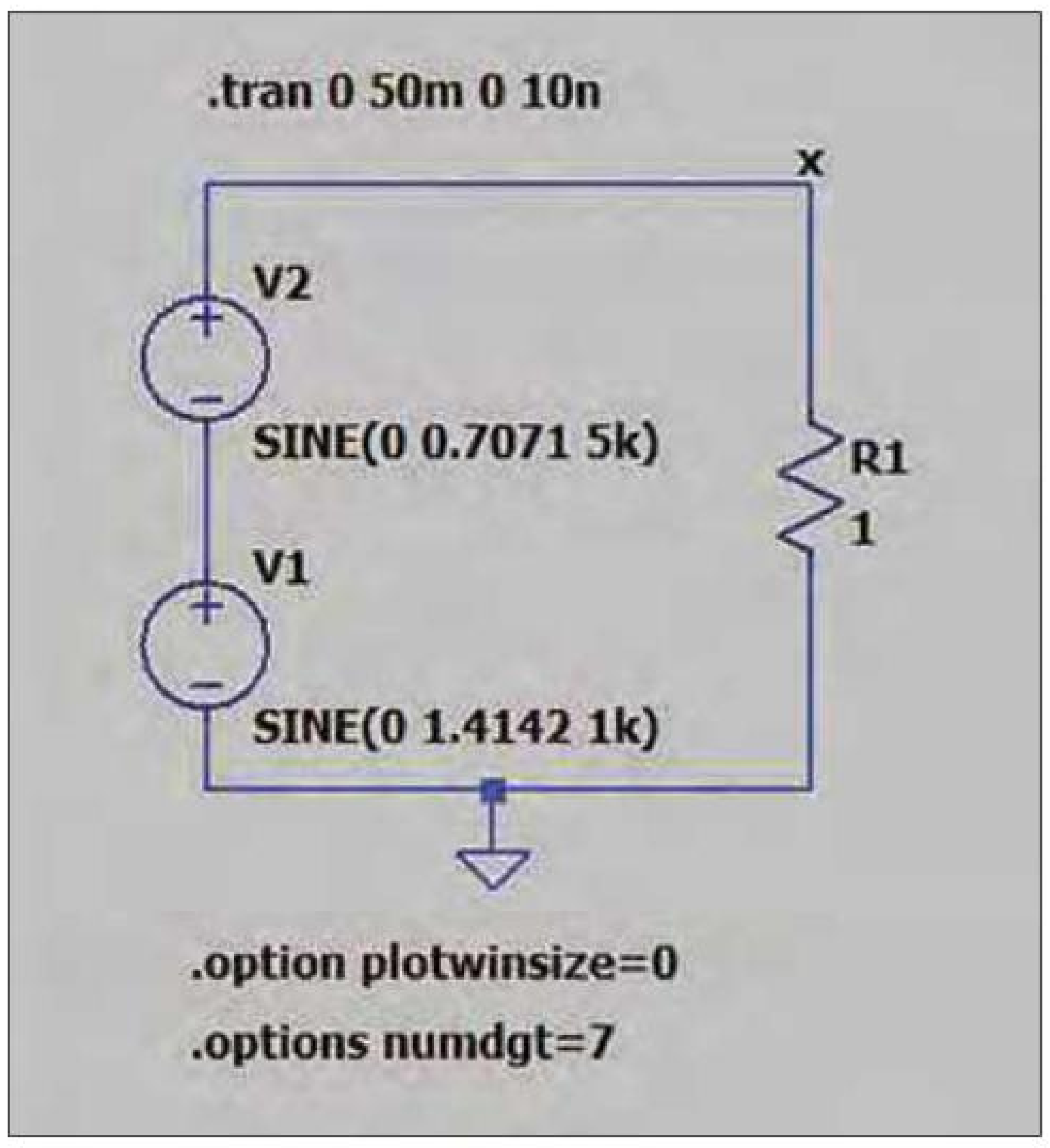


Fig.8. Further improvements in accuracy using double-precision maths.



```
.tran 0 50m 0 10n
.option plotwinsize=0
.options numdgt=7
```

Fig.9. Generating two sinewaves at 1kHz and 5kHz.

This is added to the schematic in the same way the `plotwinsize` directive used earlier. The LTspice help informs us that historically (in SPICE) this was used to set the number of significant figures used for output data, but in LTspice setting `numdgt` greater than 6 causes double-precision maths to be used in calculations.

Plotting

Once a good quality spectrum has been obtained it is not essential to include the noise floor in the plot. For results such as those in Fig.8, the noise is so small that it is not relevant, and we can limit the decibel range to values close to the peak. This makes it easier to see the relative levels of different peaks. For example, Fig.9 shows a circuit to create a signal comprising two sinewaves, from sources `V1` and `V2` at 1kHz and 5kHz respectively. The 1kHz signal has twice the amplitude of the 5kHz one. This figure also illustrates use of the `.plotwinsize` and `.numdgt` directives discussed above.

Plotting the results from Fig.9 using the full decibel range (as in Fig.8) makes it difficult to see the relative amplitude of the two frequencies. The plot in Fig.10 is the FFT results from the circuit in Fig.9 with the decibel range set to more convenient values. From this we can clearly see that the 5kHz signal (`V2`) is 6dB below the 1kHz signal (`V1`). This is a signal amplitude ratio of 20log(`V2`/`V1`) = –6dB or `V1`/`V2` = $10^{-6/20}$ = 0.5, that is the 5kHz signal is at half the amplitude of the 1kHz signal, as we woud expect from the source configurations.

This brings us to an issue which sometimes confuses people: what exactly the FFT result is plotting. The `V1` source in Fig.9 has an amplitude of 1.4142V (√2). This value was chosen because it represents an RMS (root mean square) AC voltage of 1V. The RMS value of an AC voltage is the value of the DC voltage which would dissipate the same power in a given resistor and represents an average of the power delivered over a waveform cycle. For a sinewave, the RMS value is the peak value divided by √2. The default LTspice FFT plot is in dBV – that is, decibels relative to $1V_{rms}$, specifically $20\log(V_{rms}/1V_{rms})$, so 1.4142 (1Vrms) is plotted as 0dB (20log(1)) and 0.7071V as –6dB (20log(0.5)), as shown in Fig.10. The FFT plot can also be set up to display RMS values instead of decibels by right-clicking the amplitude axis and selecting Linear in the Representation section. This version of the plot in Fig.10 is shown in Fig.11.

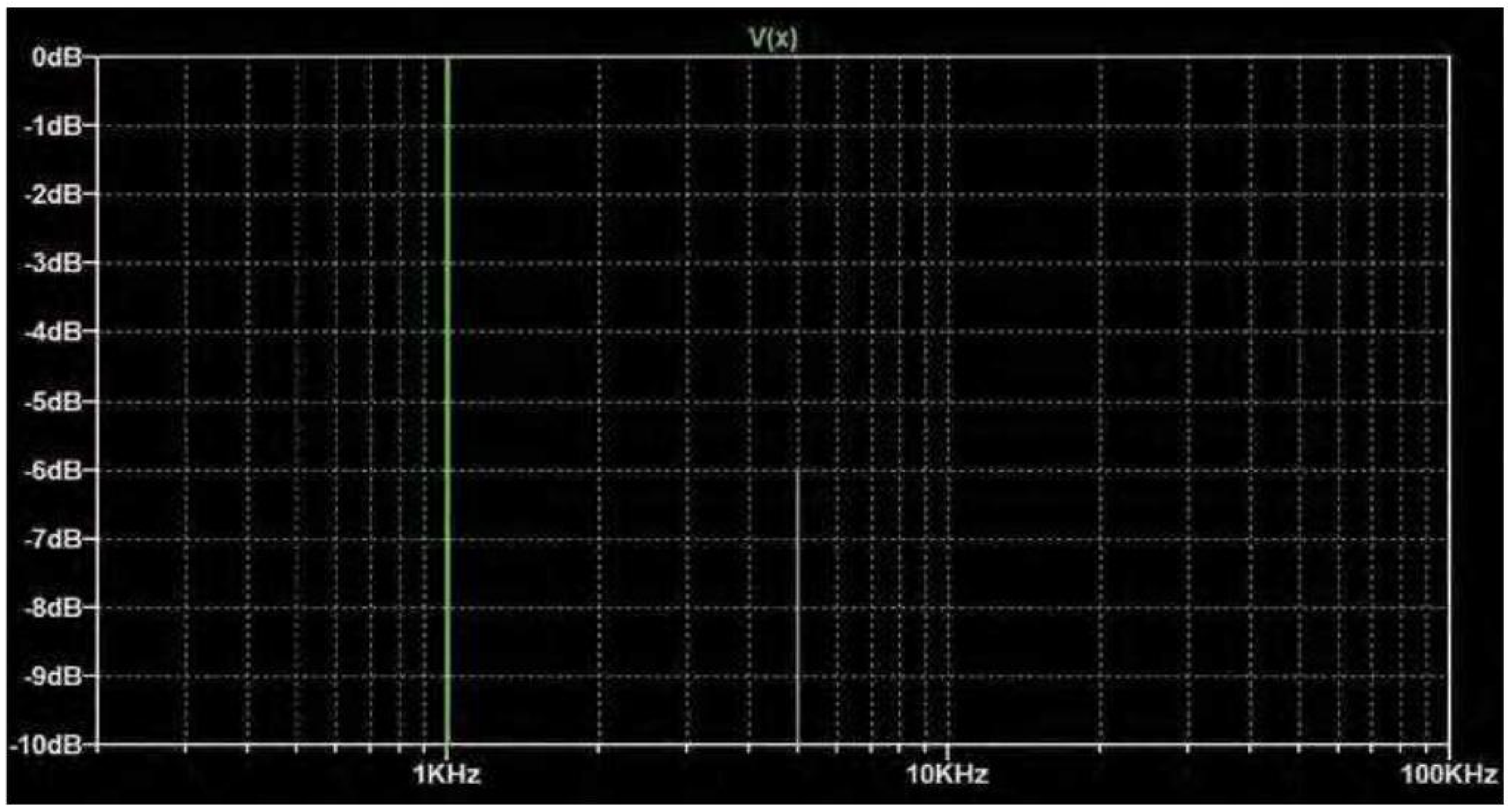


Fig.10. Results from simulation of the circuit in Fig.9.

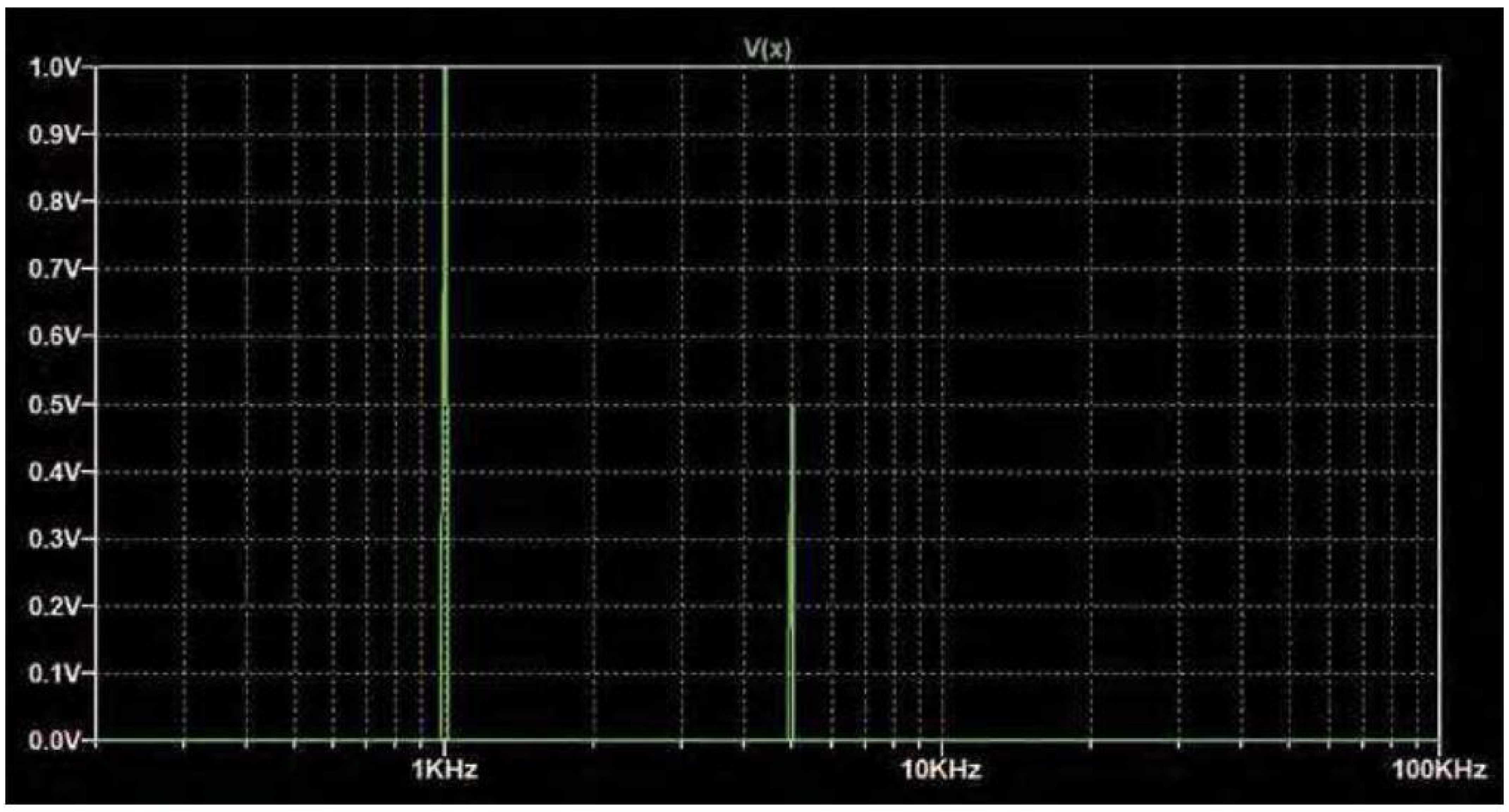


Fig.11. Linear (voltage) plot of the results from simulation of circuit in Fig.9.

FFT settings

The FFT dialog (Fig.3) provides a variety of settings which we can use to control

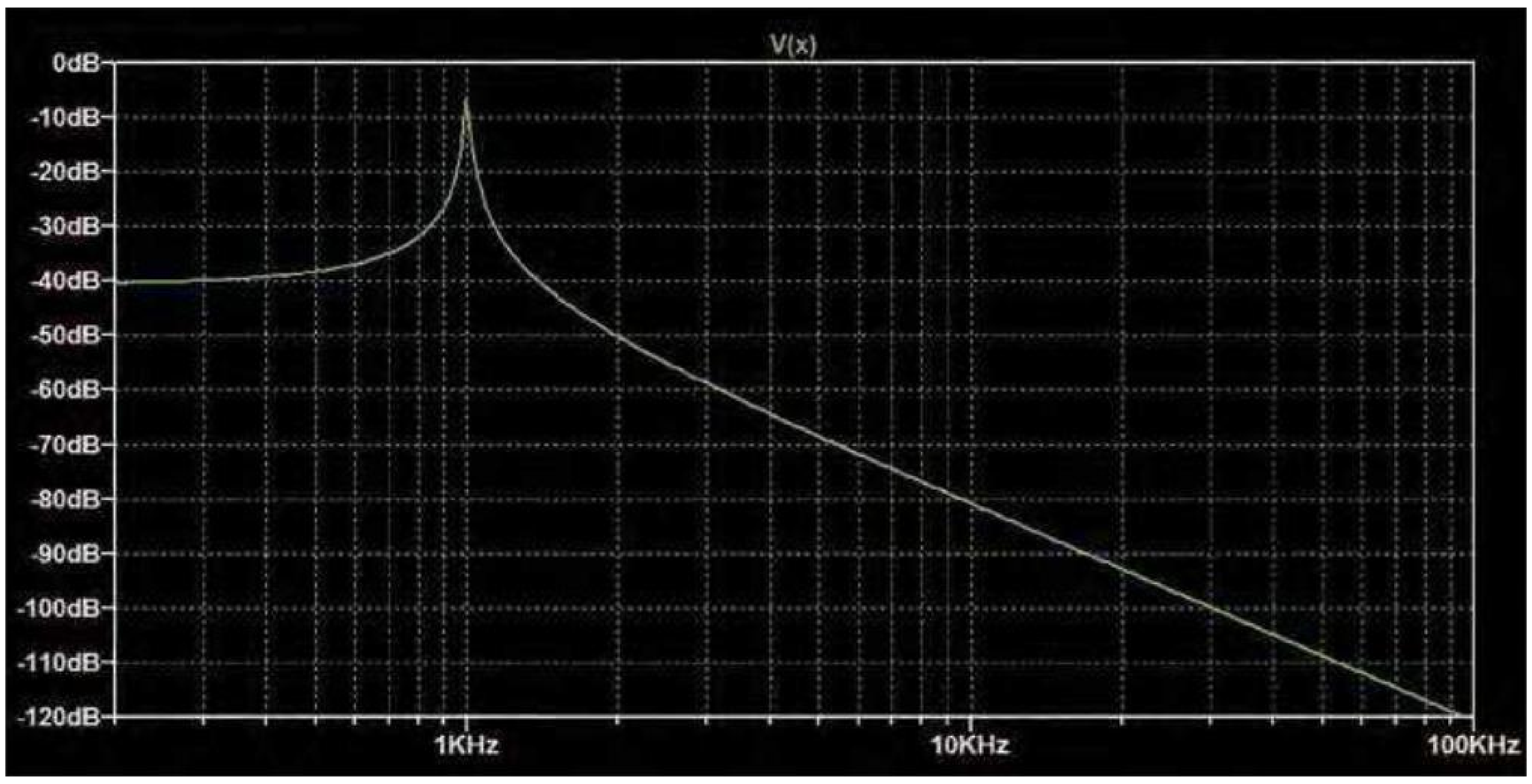
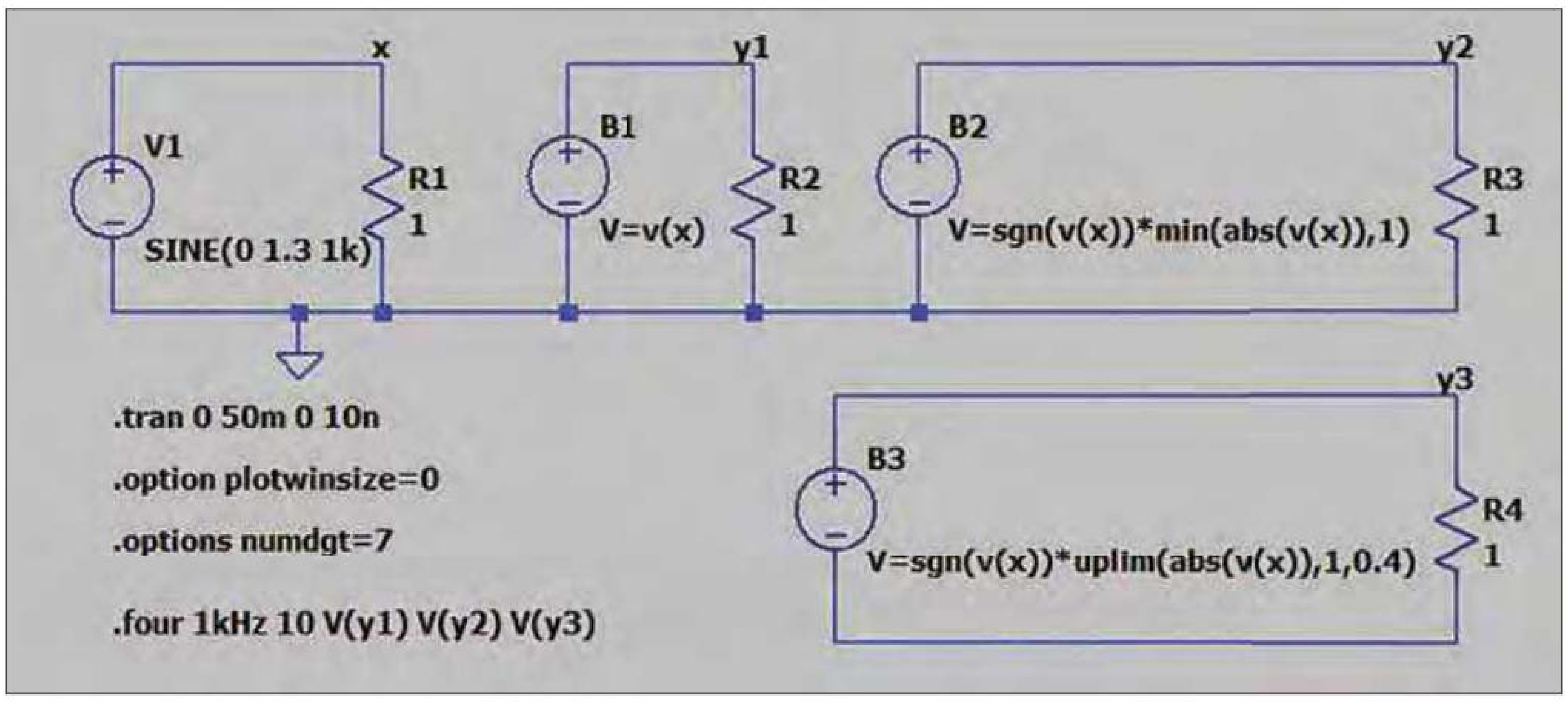


Fig.12. Using the wrong time range for a periodic signal produces an inaccurate spectrum.

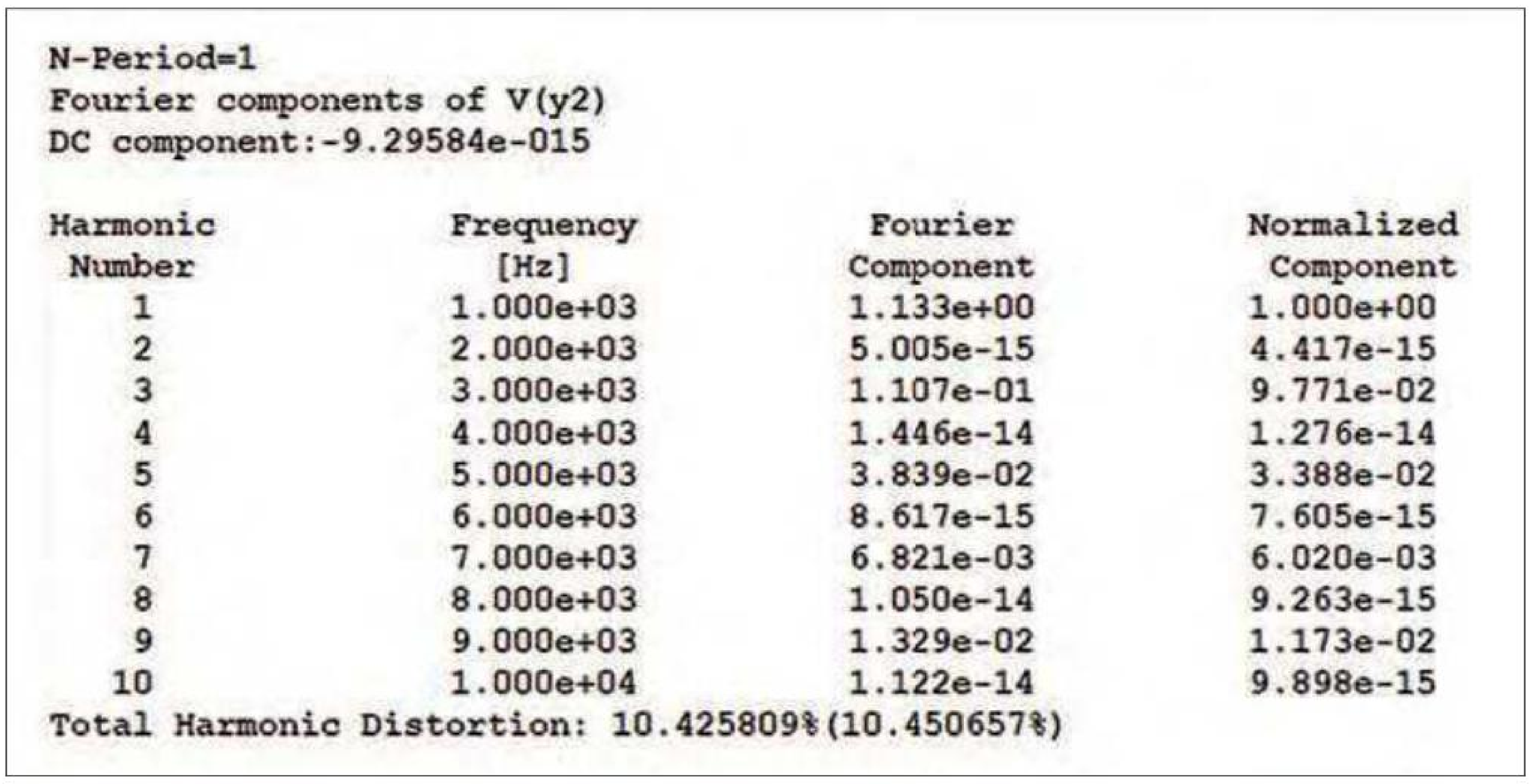
the way in which the FFT is calculated. So far, we have only used the default settings. The number of samples used by the FFT can be changed. The default is 262144. Increasing this value will slow the FFT calculation but increase the maximum frequency for which the spectrum is valid (for a given time range of data used by the FFT). The transient simulation maximum time step should be sufficiently small when extending the FFT frequency range. As we are using a low frequency here the number of points can be reduced and still provide a reasonable spectrum. However, the accuracy will also reduce, so the peak may get wider and the noise floor higher.

The time range over which the FFT is calculated (the window) can have a significant impact on the results, particularly for periodic waveforms like our sinewave. For such waveforms the range should be an exact number of waveform cycles. The FFT is effectively calculated on a waveform which is made up of infinitely repeated copies of the window range. Discontinuities at the ends of the range introduce errors into the spectrum – this is known as ‘spectral leakage’.


x
y1
y2
y3
V1
R1
1
SINE(0 1.3 1k)
B1
V=v(x)
R2
1
B2
V=sgn(v(x))*min(abs(v(x)),1)
R3
1
B3
V=sgn(v(x))*uplim(abs(v(x)),1,0.4)
R4
1

```
.tran 0 50m 0 10n
.option plotwinsize=0
.options numdgt=7
.four 1kHz 10 V(y1) V(y2) V(y3)
```

Fig.13. LTspice schematic for example THD analysis.



```
N-Period=1
Fourier components of V(y2)
DC component:-9.29584e-015

Harmonic      Frequency      Fourier      Normalized
 Number         [Hz]        Component      Component
    1        1.000e+03      1.133e+00      1.000e+00
    2        2.000e+03      5.005e-15      4.417e-15
    3        3.000e+03      1.107e-01      9.771e-02
    4        4.000e+03      1.446e-14      1.276e-14
    5        5.000e+03      3.839e-02      3.388e-02
    6        6.000e+03      8.617e-15      7.605e-15
    7        7.000e+03      6.821e-03      6.020e-03
    8        8.000e+03      1.050e-14      9.263e-15
    9        9.000e+03      1.329e-02      1.173e-02
   10        1.000e+04      1.122e-14      9.898e-15
Total Harmonic Distortion: 10.425809%(10.450657%)
```

Fig.14. Fourier component and THD analysis results for signal `y2` in Fig.13.

By default, the entire simulation is used for the FFT. This may not be the best approach to use; for example, if a circuit takes several cycles to stabilise, it would be best to start any FFT analysis after this. The FFT time range can be set in LTspice by zooming in on the waveform, or by typing in specific time values. To try this, open the FFT dialog again and select ‘Specify a time range’ in the ‘Time range to include’ section. Change the ‘End time’ from `50ms` to `49.5ms` and click OK to obtain the spectrum. It will look like Fig.12. The peak is wide and slopes off slowly.

If the signal is not periodic, windowing functions can be used to ‘fade out’ the edges of the time range to prevent any discontinuities causing spectral leakage. Normally, these would not be needed for periodic waveforms such as sines – if we correctly used an exact number of cycles.

THD Analysis

LTspice is able to perform THD analysis. Fig.13 shows the circuit from last month which we used to illustrate the output spectra from a couple of nonlinear functions. It is a good idea to check that the spectrum looks reasonable (using the FFT plot) before looking at THD results to make sure that the results will be valid. The `.four` SPICE directive on the schematic shown in Fig.13 instructs LTspice to perform a Fourier component and THD analysis on a periodic signal. The syntax of the `.four` directive is

```
.four <frequency> [Nharmonics]
[Nperiods] <data trace1> [<data
trace2> ...]
```

The frequency parameter specifies the fundamental frequency for which the analysis is performed. This will usually be the fundamental frequency of the input signal. `Nharmonics` specifies the number of harmonics for which the Fourier components will be calculated (the default is 9). `Nperiods` specifies how many waveform periods back from the end of the simulation are used to perform the analysis. The default setting is 1, but changing to –1 causes the entire simulation to be used. The example in Fig.13 is:

```
.four 1kHz 10 V(y1) V(y2) V(y3)
```

This calculates ten Fourier components for a fundamental of 1kHz for signals `y1`, `y2` and `y3` using one waveform period. The results are accessed using View -> Spice Error Log. A table listing part of the results from the circuit in Fig.13 is shown in Fig.14. The THD for signal `y2` is 10.4%.

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Note '10/63' denotes '10μF 63V'.

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22/35, 33/35, 47/20, 68/15, 100/10, 150/6	£1.25
4.7/50, 6.8/35, 10/25, 10/35, 22/15	£1.00

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Lots of big valve resistors available.

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AUDIO OUT

By Jake Rothman

Transformers in audio – Part 1

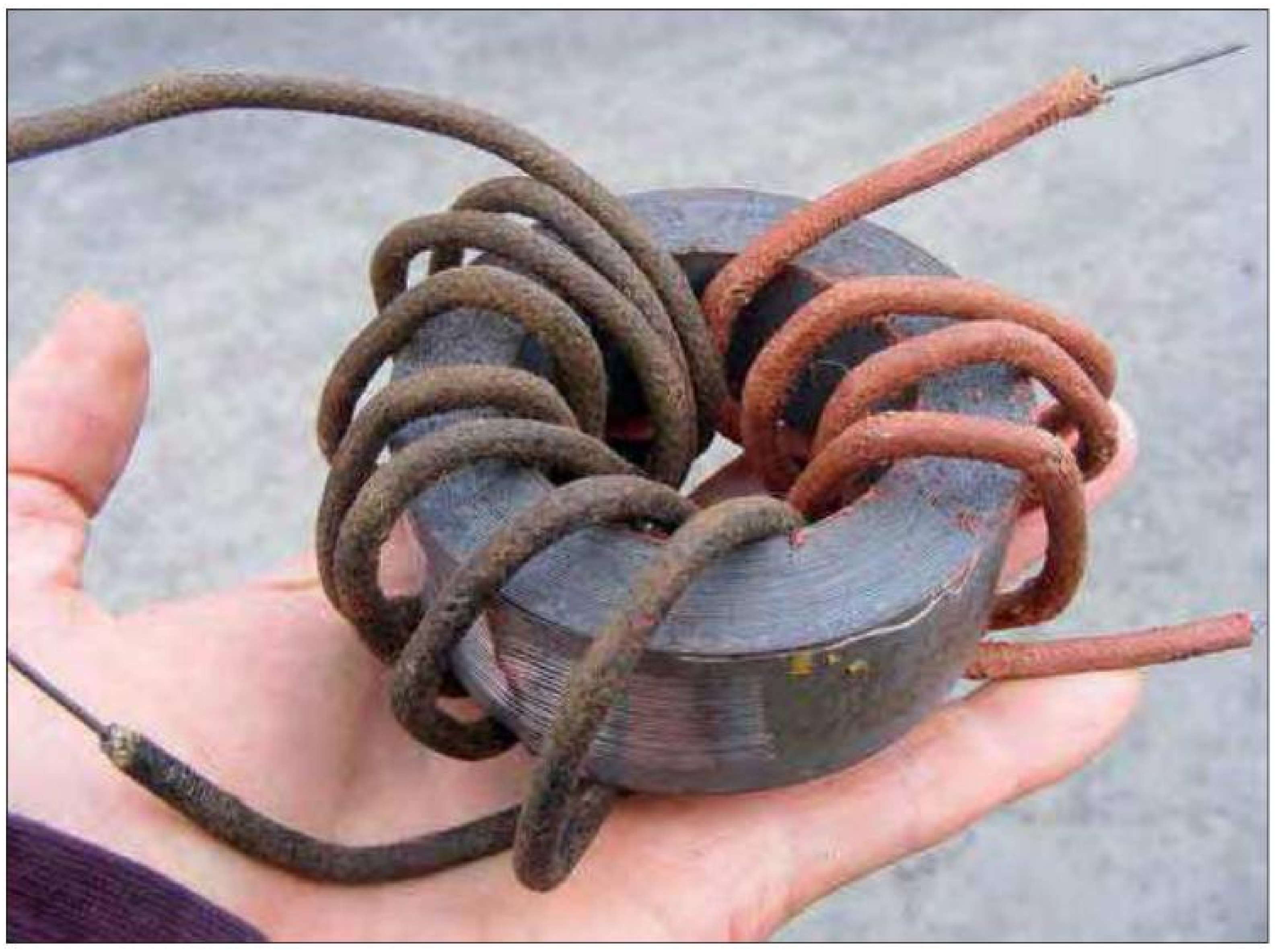


Fig.1. A reconstruction of Faraday's original transformer. Two coils on an iron ring. The cloth covered wire is from under the floorboards of my 1901-built Rectory. The clergy were at the forefront of technology back then.

The transformer has always had a vital role in audio electronics – right from the start of audio technology with Victorian telephone systems up to the latest studio digital-to-analogue converters. The transformer can trace its lineage directly from Faraday's 1831 law of electromagnetic induction, which states that voltage is proportional to the rate of change of magnetic flux ($V = \mathrm{d}\Phi/\mathrm{d}t$ where Φ is the magnetic flux). Later, Faraday made the first original transformer with two coils of cotton-covered wire wound on an iron ring (similar to the one in Fig.1), although he only used it to demonstrate kicks on a compass. True transformer action based on mutual induction was not revealed until around 1836. I'm still amazed when I see a toroidal transformer in a modern Hi-Fi amplifier, as illustrated in Fig.2. It must be one of the oldest, and least-changed electronic components still in production nearly two centuries after it was invented. Toroidal transformers are regarded as the best choice for audio power supplies by audiophiles because of their low emitted noise. Commercial switch-mode power supplies are (often) much cheaper and more compact, but they have short lives and add high-frequency noise on top of mains frequency noise.

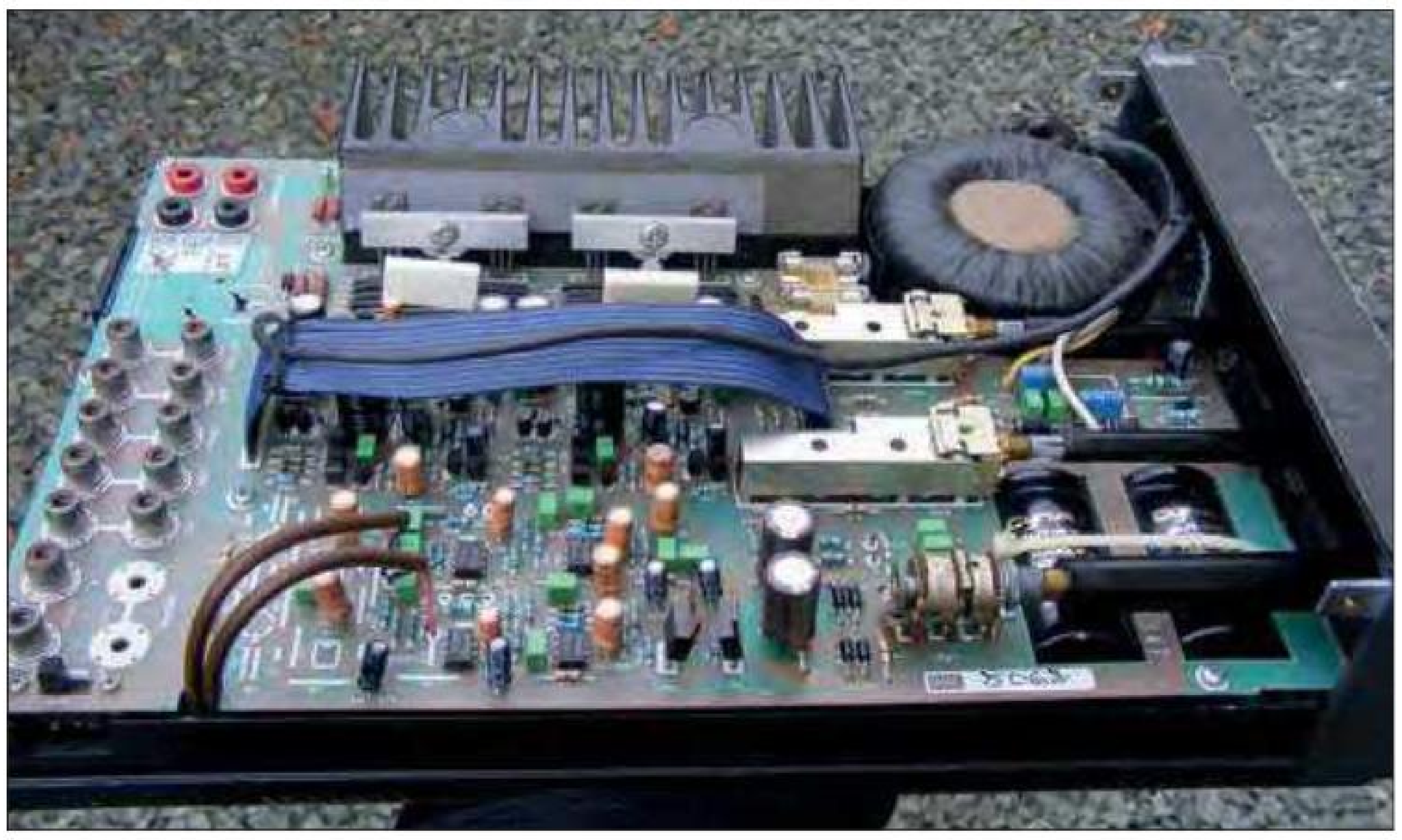


Fig.2. Faraday's transformer still lives on in modern amplifiers. Top-right, a 28-0-28V 100VA toroid in a Cyrus 2 amplifier made by Holden and Fisher.

It's important to note that when we say 'audio transformer' there are two basic kinds – 'power transformers', which are found in power supplies, and 'signal transformers' which range from tiny input transformers to large high-power amplifier output transformers. We will cover both types.

There is no alternative

Modern audio (low) frequency transformers are still made from copper, iron and nickel; and their cost generally follows commodity price ups and downs. They are also big and heavy. Accountants regard them as an anachronism to be eliminated, and favour silicon devices, which benefit from mass production and are much more resilient in terms of raw materials pricing. Audio engineers, however, appreciate the total electrical isolation transformers provide between one circuit and another. This eliminates the risk of interference, hum loops and domino destruction effects. I've been to many a design meeting arguing to include them in a product, often to be met with 'can't you do it with op amps, opto-isolators or simulate the transfer function in software?' The answer is always, 'no not really'. By transferring electrical energy and signals via a magnetic circuit, there is no direct wired connection, which is why Britain's Health and Safety Directorate does not recognise a sliver of reverse-biased silicon as offering viable fail-safe isolation. Also, impedance matching – varying the relative output voltage and current of a circuit – is best accomplished with a transformer, thereby optimising power transfer and noise minimisation.

Linear thinking

Unlike opto-isolators, transformers are relatively linear. Their small inherent non-linearity generates the 'transformer sound', a distortion characteristic of magnetic systems beloved by producers of electronic and pop music. With the rise of digital recording, the distortion from magnetic tape is now no more, so today this is provided by transformers. Software plug-ins can simulate it to a degree, but these don't seem to have caught on.

Long life

Transformers are one of the longest-lived electronic components. After all, there is not much to go wrong apart from a wire breaking or shorting and this can usually be fixed with a bit of rewinding. There is one exception, and that is the transformer with an internal non-resettable thermal fuse embedded in the windings. These have a short fatigue life and cause more transformers to go to landfill than anything else. The good thing is that being made out of metal, transformers are truly recyclable. I'm always surprised how much cash I get from scrap merchants from the pile of failed devices I build up every few years. It is quite common to see old amplifiers where every part has been replaced – except for the transformers and the metalwork. I always reuse old audio transformers and toroids.

Primary and secondary characteristics

Unlike most semiconductors, the transformer is a simple device and its design and application follow simple repeatable, scalable maths. Like most Victorian technology, its physics is classical, rather than semiconductors' quantum nature. It's simply the electrical version of a gear box; voltage can be thought of as speed, and current as torque. When you change gear in a car, an optimum 'impedance match' between the engine speed and road speed is being achieved. Just as with gear ratios, transformers have voltage ratios, determined by the relative number of turns on the two windings. To put it simply, a transformer with twice as many turns on the output winding as the input winding will double the output voltage. This is called the 'turns ratio', a vital transformer parameter, and in this case, it would be expressed as 1:2. However, there is no such thing as free energy, so to preserve the energy balance between input and output, the output current is proportionally reduced. Overall, the energy transfer efficiency of well-made small power transformers is high, typically over 90%. (For very large grid transformers, operating with megawatts of power, the efficiency can approach 99.75%, making them just about the most efficient of all machines.)

The input winding of a transformer is called the 'primary' and the output winding the 'secondary'. These terms are merely designations, a transformer is inherently bidirectional and can be used both ways – but do watch out for voltage ratings. If it increases the voltage, it is called a 'step-up' transformer and for a decrease, 'step down'.

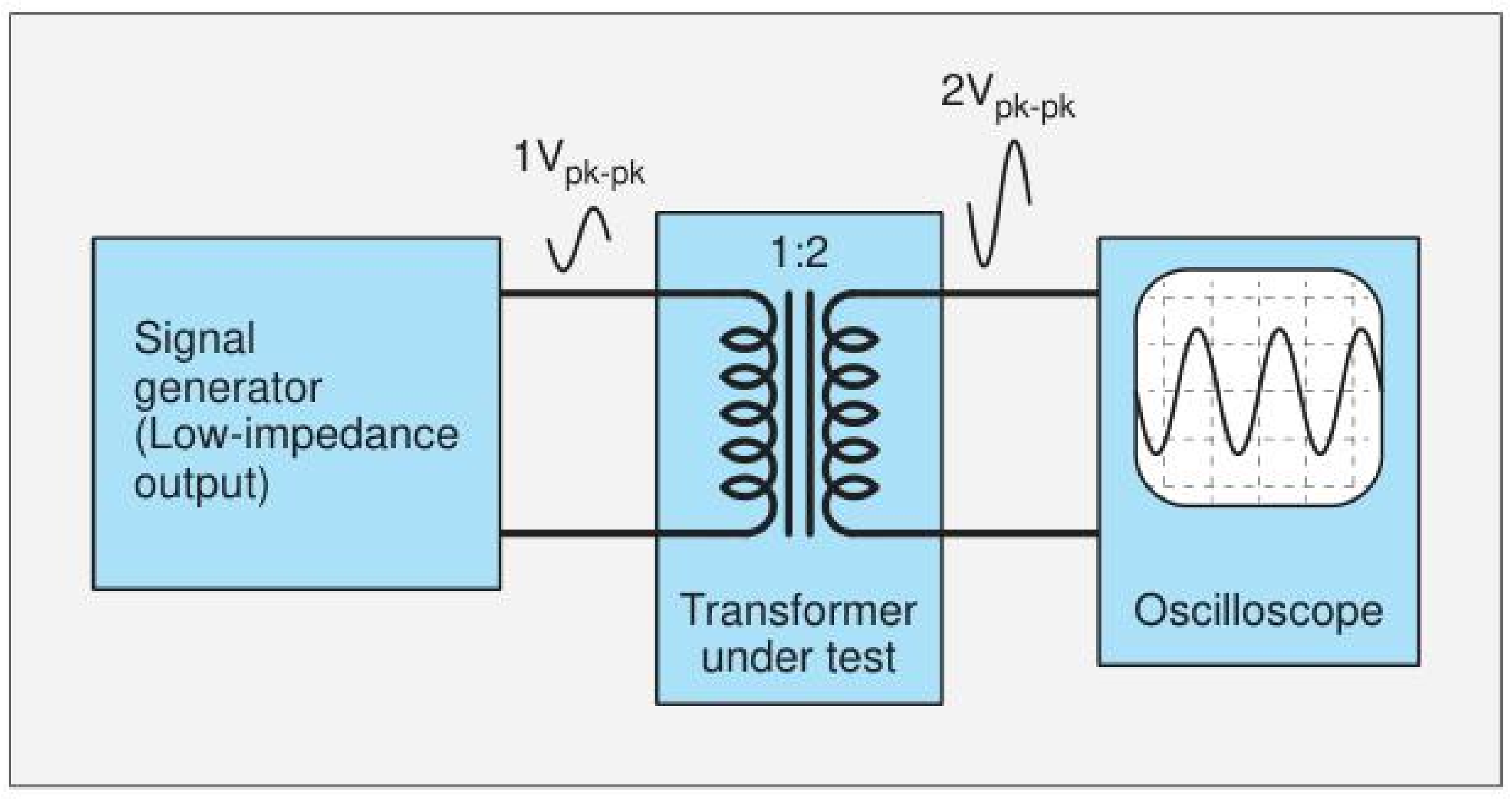


Fig.3. Measuring the turns ratio by determining the voltage ratio using a 'scope and signal generator.

Calculating the turns ratio (the ratio of primary turns (N_P) to secondary turns (N_S)) is simple. For example, a transformer with 1000 turns on the primary and 100 turns on the secondary has a 10 to 1 ratio, expressed as '10:1'. However, since it is just a ratio, a transformer with 50 turns on the primary and five on the secondary is also a 10:1 device. The absolute number of turns depends on the application. High-voltage, low-current (high-impedance) applications have thousands of turns of thin wire. High-current, low-voltage (low-impedance) devices have a few tens of turns of thick wire.

Not surprisingly, the turns ratio (n) equals the voltage ratio – but do note it is the reciprocal of the current ratio:

$$n = N_P/N_S = I_S/I_P$$

From the above, you can see that since:

$$N_P/N_S = I_S/I_P$$

We can rearrange rhe expression so that:

$$N_P I_P = N_S I_S$$

Confirming that in an (ideal) transformer, power into the primary equals power out of the secondary.

Impedance ratio and impedance matching

The turns ratio is easy to specify and understand, and also to test by looking at the voltage ratio. This can be checked with an oscilloscope and signal generator, as shown in Fig.3. You can also check the current ratio, which is *inversely proportional* to the turns ratio, but measuring currents is often less convenient than voltages.

There is another vital ratio, which is less easy to understand and analyse – the impedance ratio. The impedance ratio is the turns ratio squared – remember to square both sides, even if you are just squaring '1'. Essentially, it represents the apparent change in impedance looking from one circuit to another when linked by a transformer. In other words the output and input impedances can be modified to whatever is needed.

This is important in audio because it allows us to match the output of an amplifier to a load (eg, a speaker), or the output of a transducer (eg, a microphone) to the input of an amplifier. But why is this useful and what do we mean by matching?

When it comes to connecting an amplifier to a speaker, transformers were originally used with valve amplifiers. These typically produced high voltages

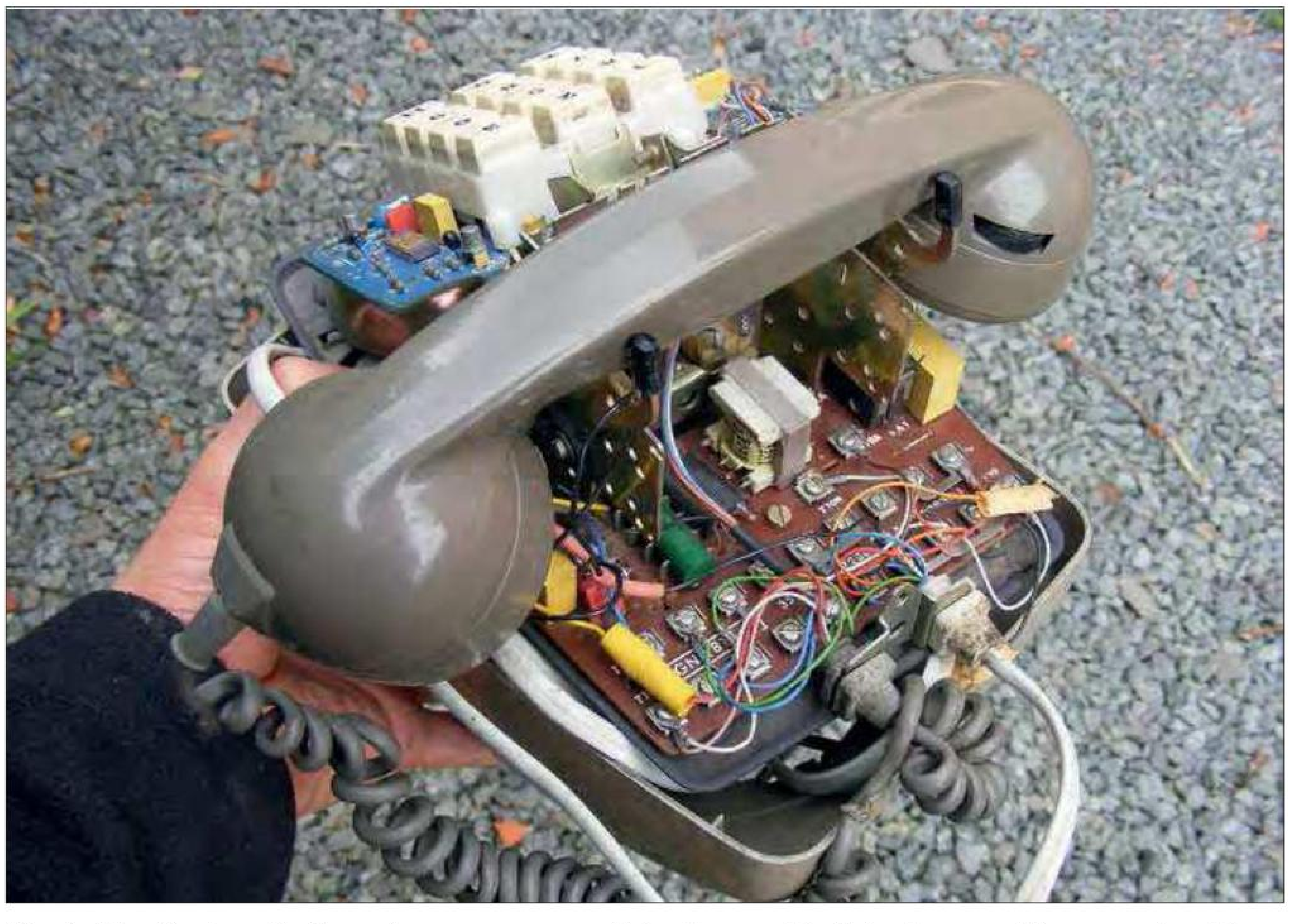


Fig.4. The first audio transformers were originally used in telephones. They survived in landlines until quite recently – here is one from a British Telecom phone from 1981. It was used for impedance matching and partial sidetone cancellation (sidetone is one's own voice in the earpiece).

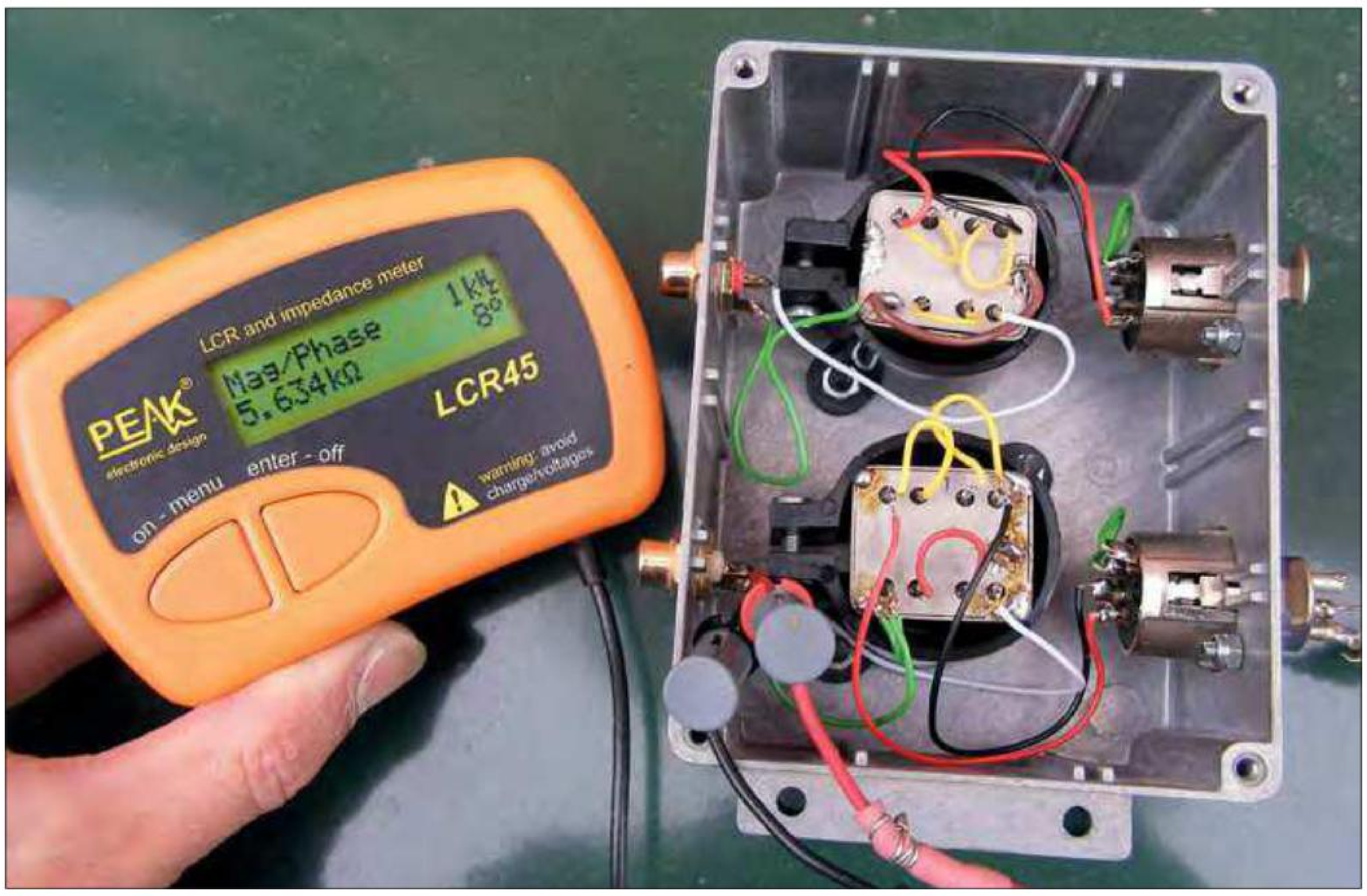

LCR and impedance meter
Mag/Phase
5.634kΩ
1kHz
8°
PEAK electronic design
LCR45
on - menu
enter - off
warning: avoid charged voltages

Fig.5. An impedance meter is a good way to check transformer action. Here, the output of a low-impedance (22Ω) turntable moving coil pickup is stepped up to 5kΩ with a 14:1 transformer (Vigortronix VTX-101-003.

but low currents, which meant they had a high output impedance. Speakers work with high currents and low voltages, so they offer a low impedance. Clearly, this created an impedance *mis-match* between the output of the valve amplifier and the speaker input. In other words, in terms of power transfer the two systems are poorly matched because for maximum power transfer the two impedances should be the same. A transformer makes the output of the amplifier appear to have a lower impedance and conversely the speaker looks like a higher impedance – so, with an appropriate turns ratio (and hence impedance ratio) the two can be better matched.

When it comes to matching transducers and the inputs of amplifiers, we do the reverse – a low microphone output impedance is matched to a high amplifier input impedance. This not only optimises power transfer but more importantly optimises the SNR (signal-to-noise ratio) into an amplifier, because for a given amplifier there will be an optimum source impedance for minimum noise. An early, but long-lived example of this was in telephone systems, which needed to match the low impedance of carbon microphones with the higher impedance of long telephone lines to minimise losses. A transformer was used at the other end to match the receiver/earphone impedance. This transformer also blocked DC. Fig.4 shows the transformer in a 1981 British Telecom phone.

A good approximation to the impedance ratio can be calculated from the turns ratio, but for the best performance in a circuit you need to take into account the transformer's non-ideal characteristics, which we will cover next month. That said, the lazy (and very effective) way to find the impedance ratio is to use an impedance meter, such as the Peak LCR45 shown in Fig.5.

Multiple windings

The number of windings on a transformer need not just be limited to two, most

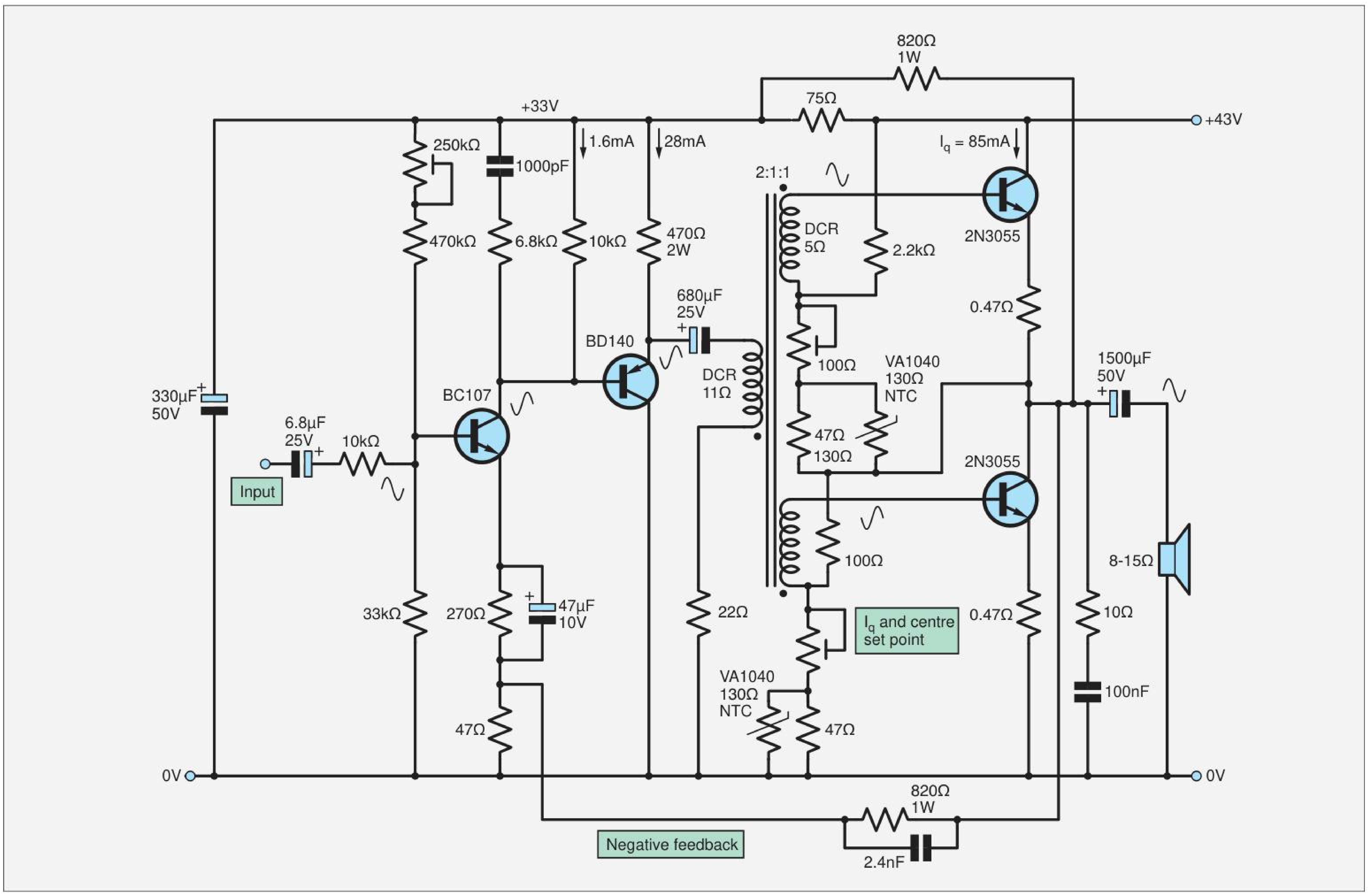

820Ω
1W
75Ω
+33V
+43V
250kΩ
1000pF
1.6mA
28mA
I_q = 85mA
2:1:1
DCR
5Ω
2.2kΩ
2N3055
470kΩ
6.8kΩ
10kΩ
470Ω
2W
680µF
25V
0.47Ω
BD140
100Ω
VA1040
130Ω
NTC
DCR
11Ω
1500µF
50V
330µF
50V
BC107
47Ω
130Ω
6.8µF
25V
10kΩ
Input
2N3055
100Ω
8-15Ω
33kΩ
270Ω
47µF
10V
22Ω
I_q and centre set point
0.47Ω
10Ω
VA1040
130Ω
NTC
100nF
47Ω
47Ω
0V
0V
820Ω
1W
Negative feedback
2.4nF

Fig.6. Push-pull driver transformer circuit from the Rogers Ravensbrook, a classic late-1960s transistor audio amplifier. The circuit shown here uses a phase splitter to allow just one polarity (NPN) of driver transistor to be used. This amplifier sounded excellent with 15Ω LS3/5A loudspeakers.

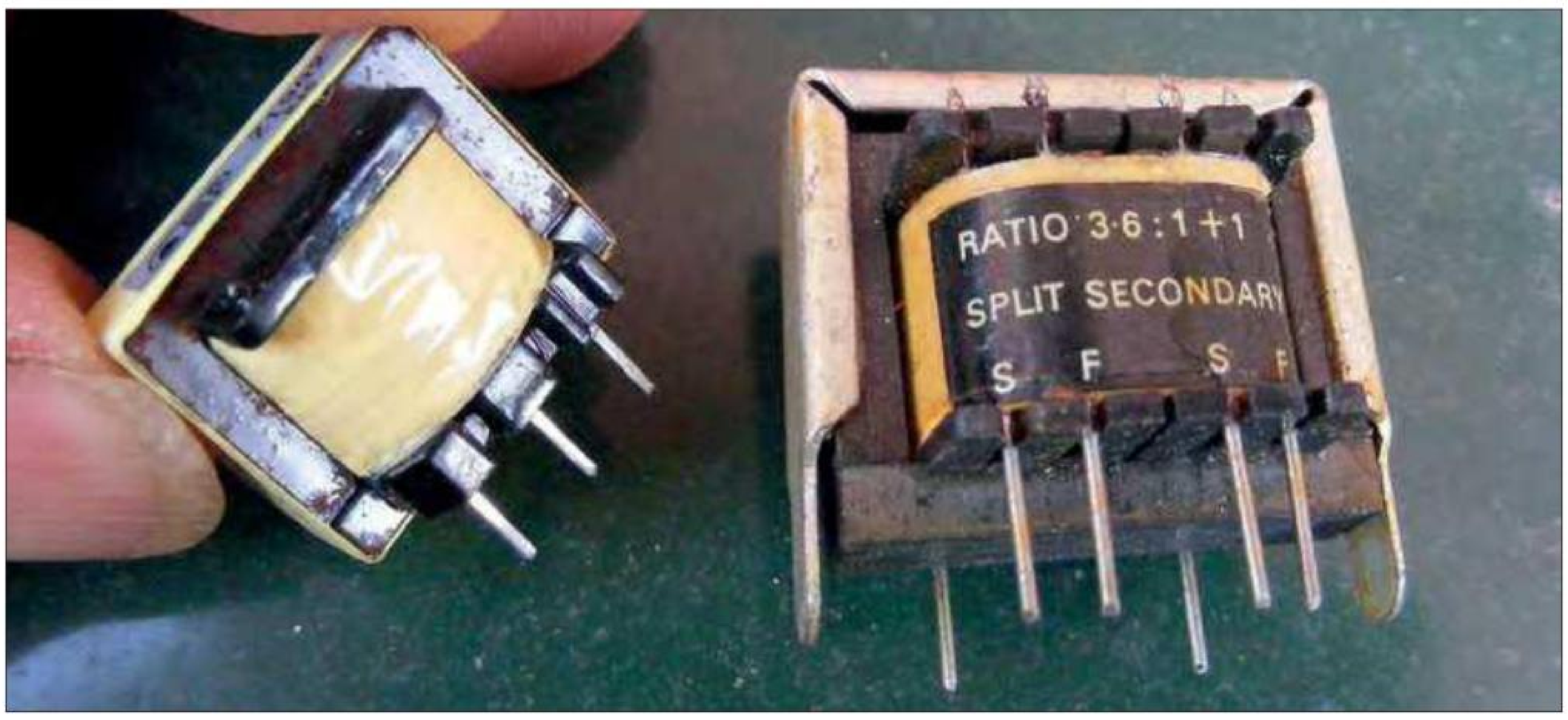


Fig.7. Push-pull driver transformers – one with a centre-tapped winding and one with split windings for output stages without a final output transformer, such as the Ravensbrook.

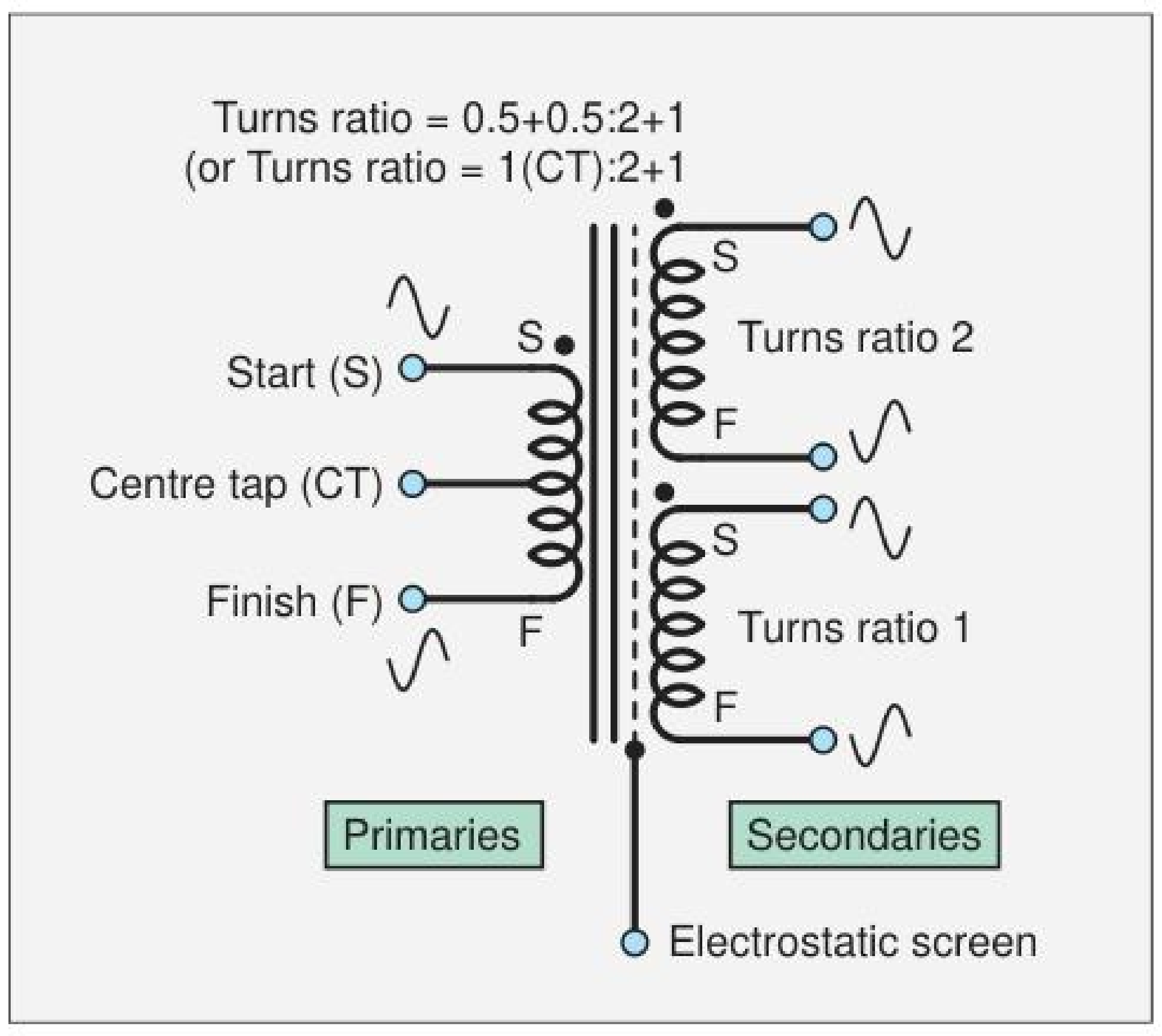


Fig.8. Phase is indicated by dots or winding start (S) and finish (F). Dot and S are the positive going half of the cycle.

types have four: two primaries and two secondaries which offer several useful combinations from one transformer. For example, with power transformers you can put the primaries in series for 240V in, or in parallel for a 120V supply. And for the secondaries, you can join the two together at one end for a centre-tapped supply, or in series for double the voltage or in parallel for double the current.

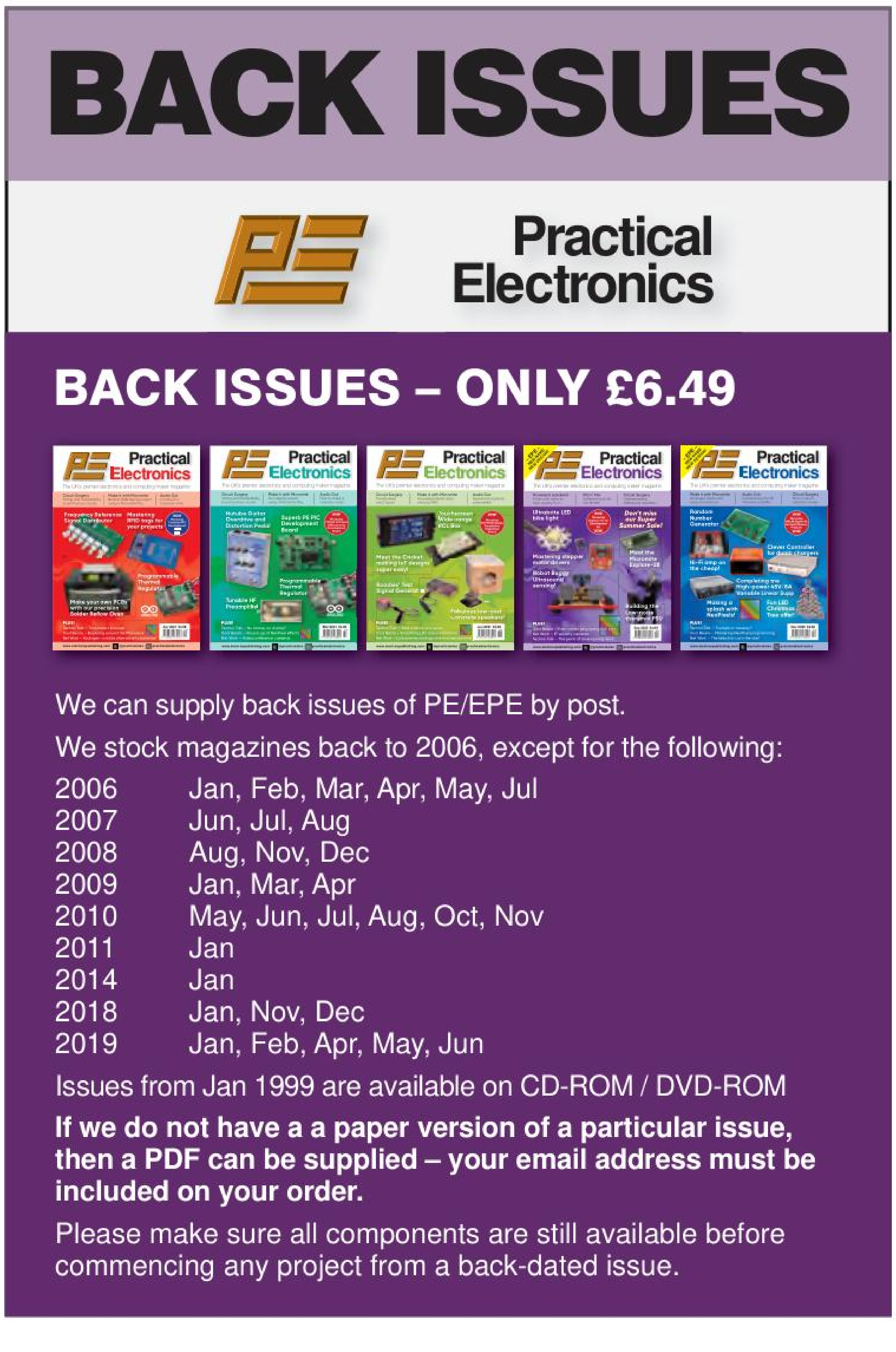
For signal transformers in audio circuits, multiple secondary tappings can provide two antiphase outputs (often called ‘phase splitting’). This was vital in early amplifiers when only one polarity of valves or early transistors was readily available for push-pull power amplifier outputs. The phase splitter transformer meant you could build a push-pull amplifier with just NPN transistors, as shown in Fig.6. (Note the phase splitter is *not* an output transformer for impedance matching with speakers.) Fig.7 shows a couple of driver transformers suitable for phase splitting.

Going dotty about phase

The phase of an AC voltage on a winding is indicated on a transformer with a dot, which indicates a positive-going cycle, as shown in Fig.8. The start and finish of a winding can also be used to indicate phasing with the initials ‘S’ and ‘F’.

Next month

In *Part 2* next month, we will look at a transformer equivalent circuit that will help us design circuits that take account of their non-ideal characteristics.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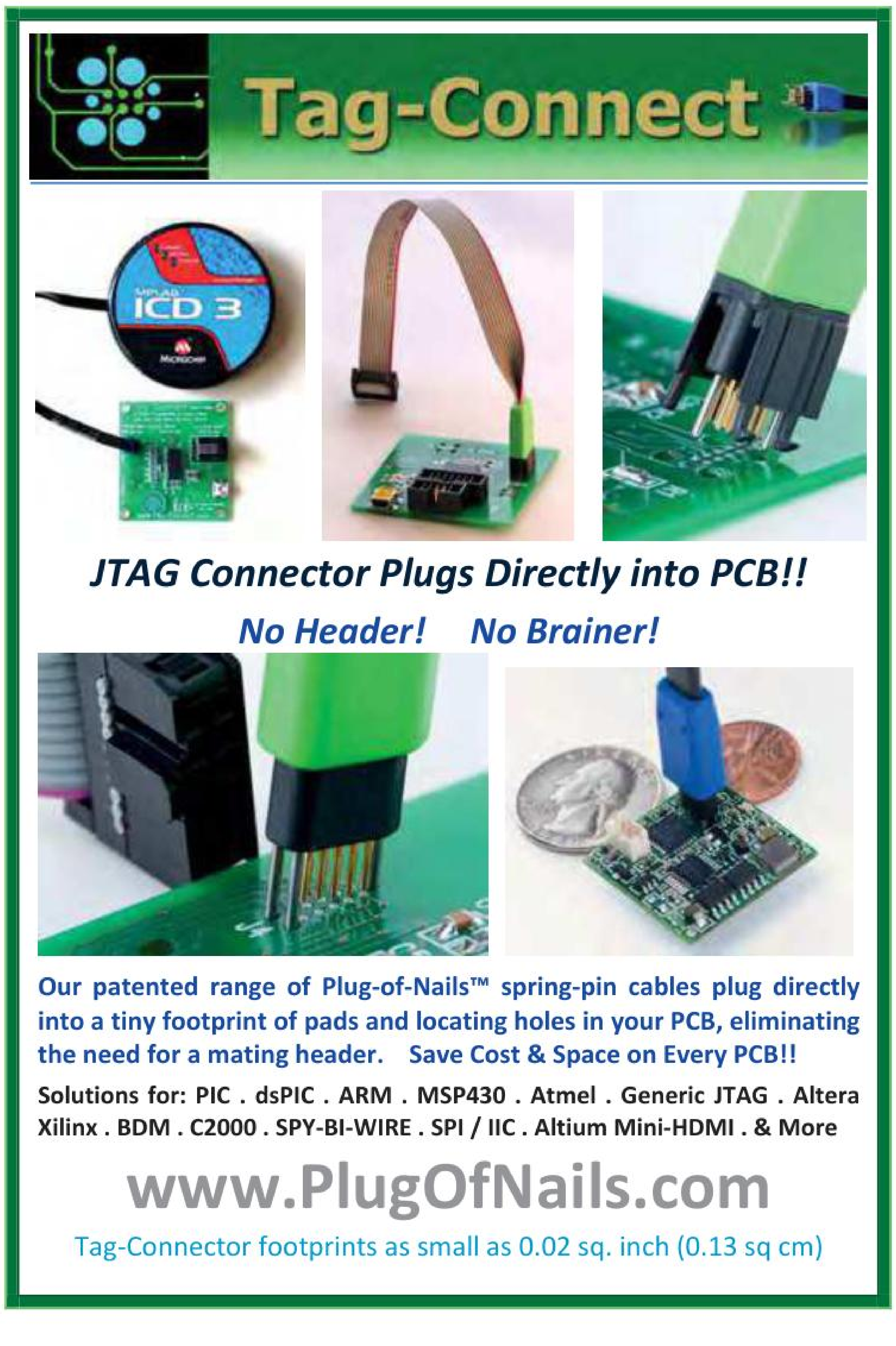
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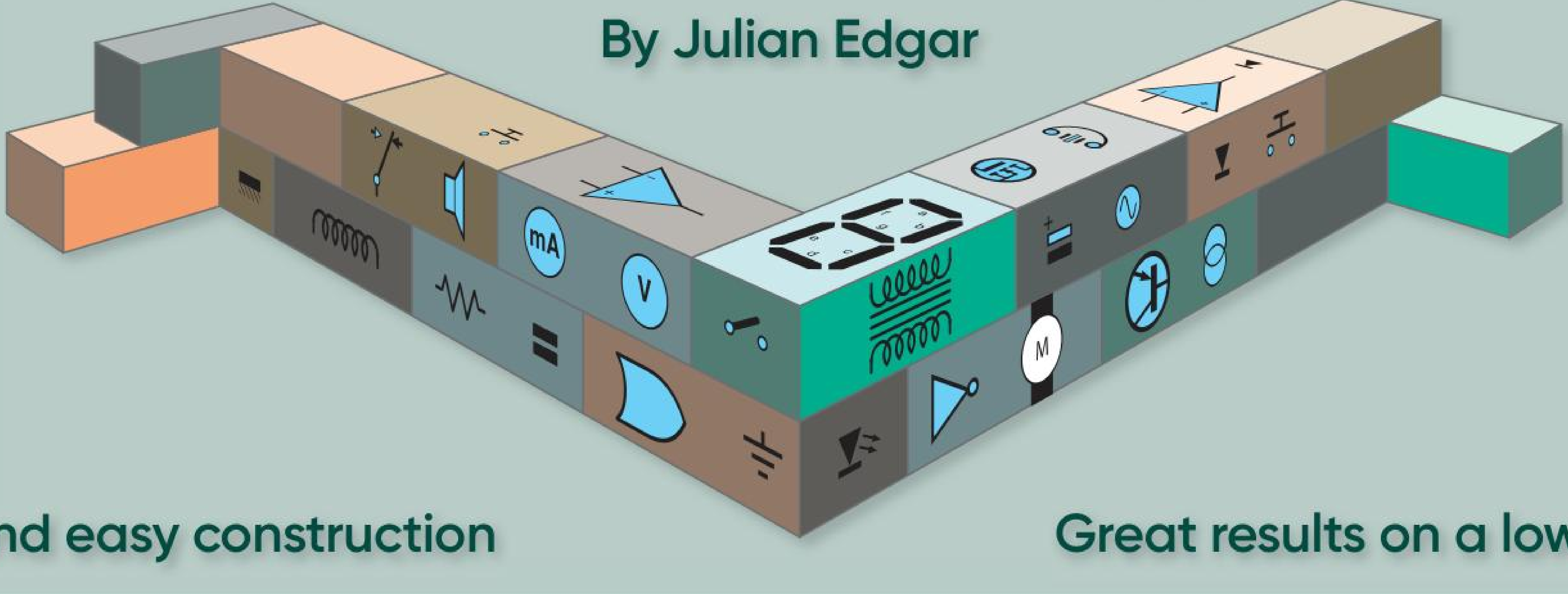


Quick and easy construction

Great results on a low budget

Introduction to linear actuators – Part 2

Controlling a linear actuator with positional accuracy using the programmable Pololu Jrk 21v3 module.

In Part 1, we looked at how linear actuators can be controlled by simple switches and relays. This approach is fine if you want the actuator to be fully open or fully closed, or you are controlling a progressive opening by physically watching the movement of the actuator (eg, shutting a gate). However, if you want more accurate control (for example, always opening the actuator by exactly 100mm) then a controller that uses position feedback is needed. So, this month, we turn to a fully programmable control module that provides excellent positional accuracy, even with varying voltage feeds and loads. In addition, the module can also control maximum speed and acceleration – and more.

Note that to make use of the feedback function, you will need to select a linear actuator that uses an internal potentiometer to provide position information. These are less common than actuators without feedback. That said, companies like AliExpress do offer them from about £30.

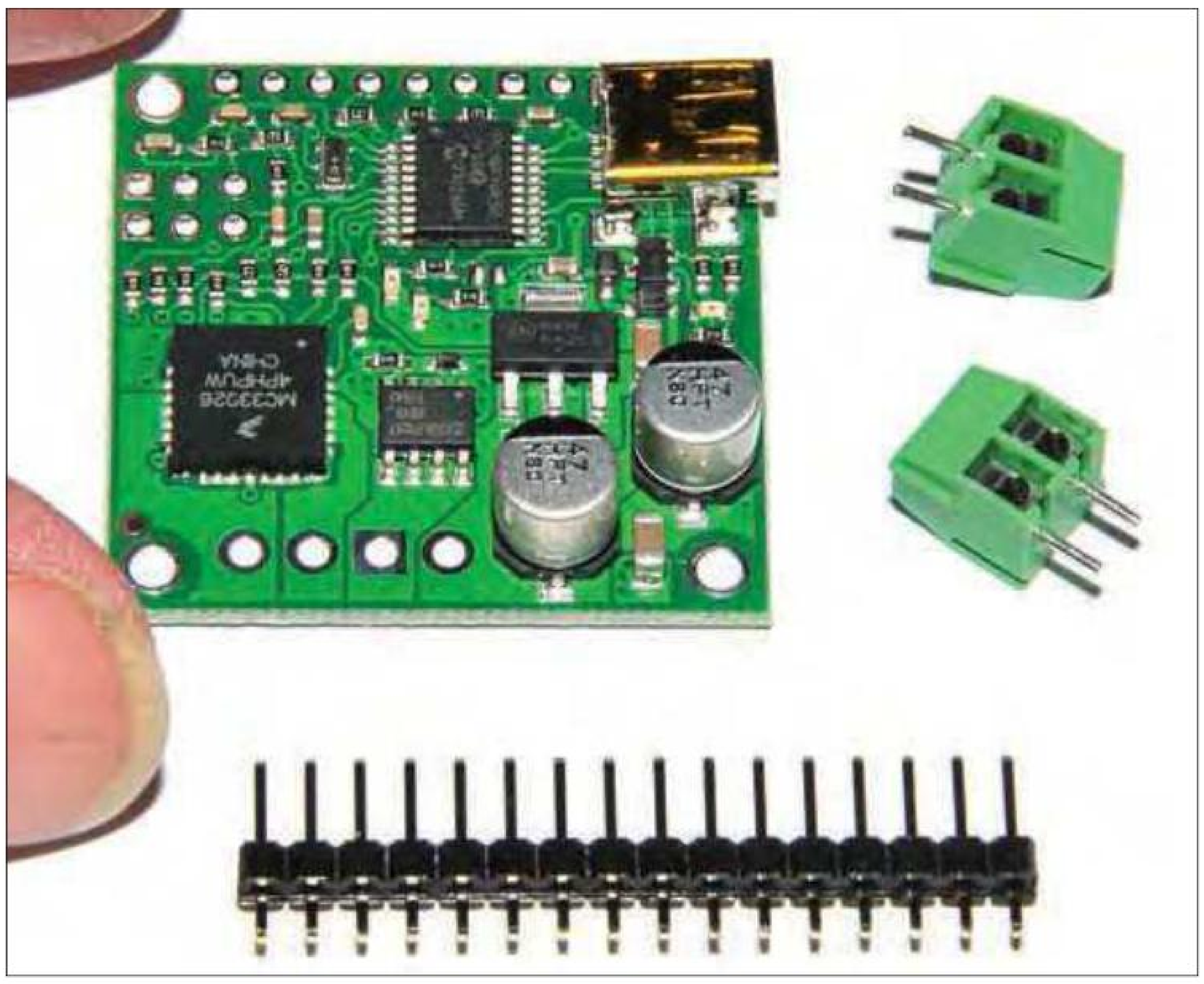


Fig.1. The Pololu Jrk 21v3 is a tiny board – just 34mm square. However, it can run brushed DC motors drawing up to a peak of 5A and can be controlled through multiple interfaces, including an analogue input, serial, PC USB link or model RC pulse train. Once programmed, it can be disconnected from the PC.

The controller

The controller we will use is the Pololu Jrk 21v3 USB Motor Controller with Feedback. It is widely available for about £40.

Now, before you blanch at that price, let's take a step back. Why, you may be thinking, don't you just use a cheap microcontroller like an Uno with a H-bridge motor drive shield? After all, you're only controlling a DC motor! Well, the key difference is the software. Unless you want to spend a lot of time writing code – and I mean a lot – then the off-the-shelf software that is freely available for the Jrk 21V3 controller provides a huge advantage over a home-grown software solution.

But before we look at the software, what does the module comprise? Measuring just 34mm square, the Jrk 21V3 is designed specifically for controlling small, brushed DC motors. Part of a family of motor controllers, the Jrk 21V3 has a maximum supply voltage of 24V and a maximum continuous current of 2.4A, with a 5A peak rating. (Higher currents are available in other controllers in the family.)

The Jrk 21V3 has four interfaces:

- USB for control via a PC
- TTL-level serial interface for microcontroller control
- Radio control (RC) PWM control for direct connection to an RC receiver or servo controller

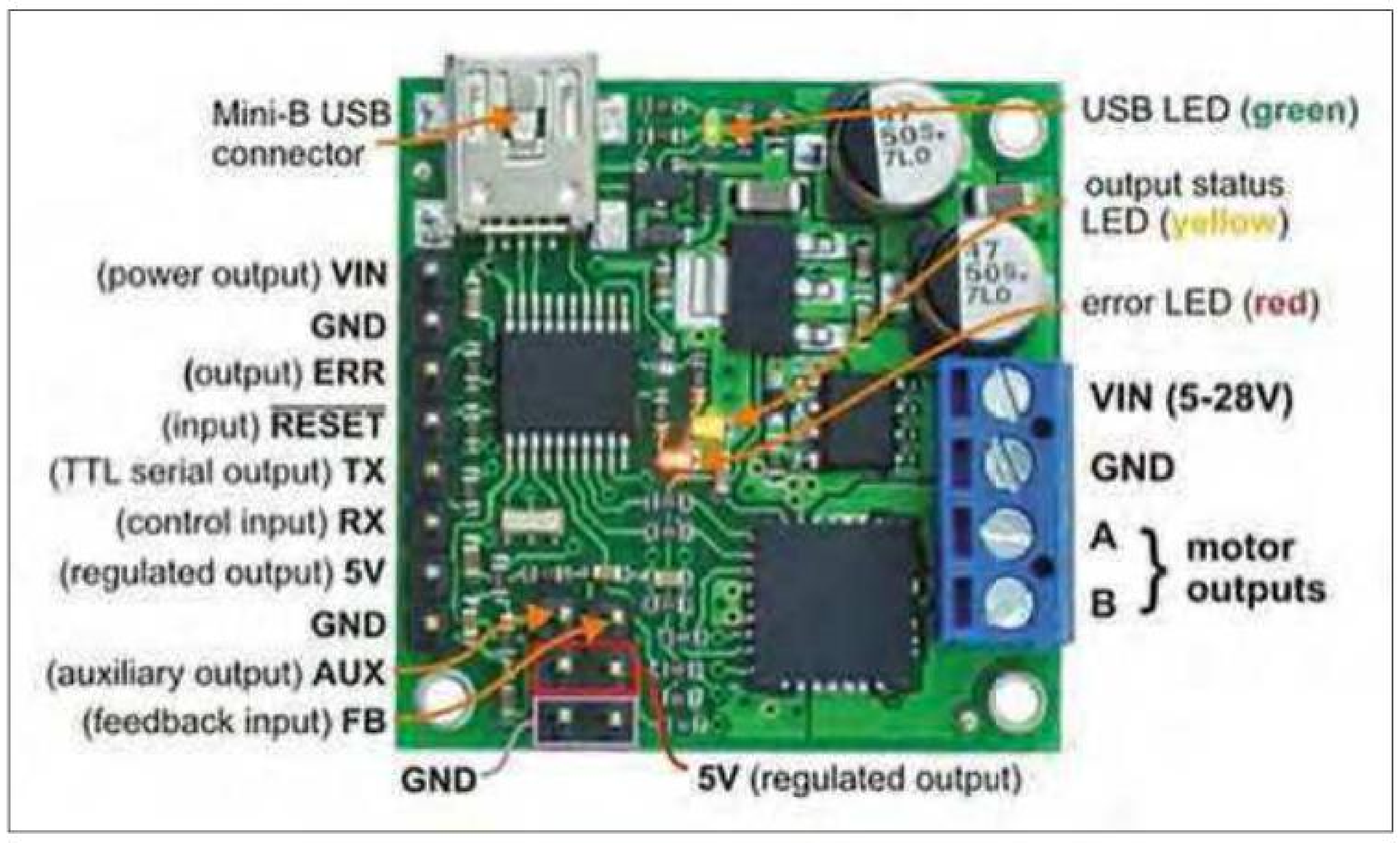
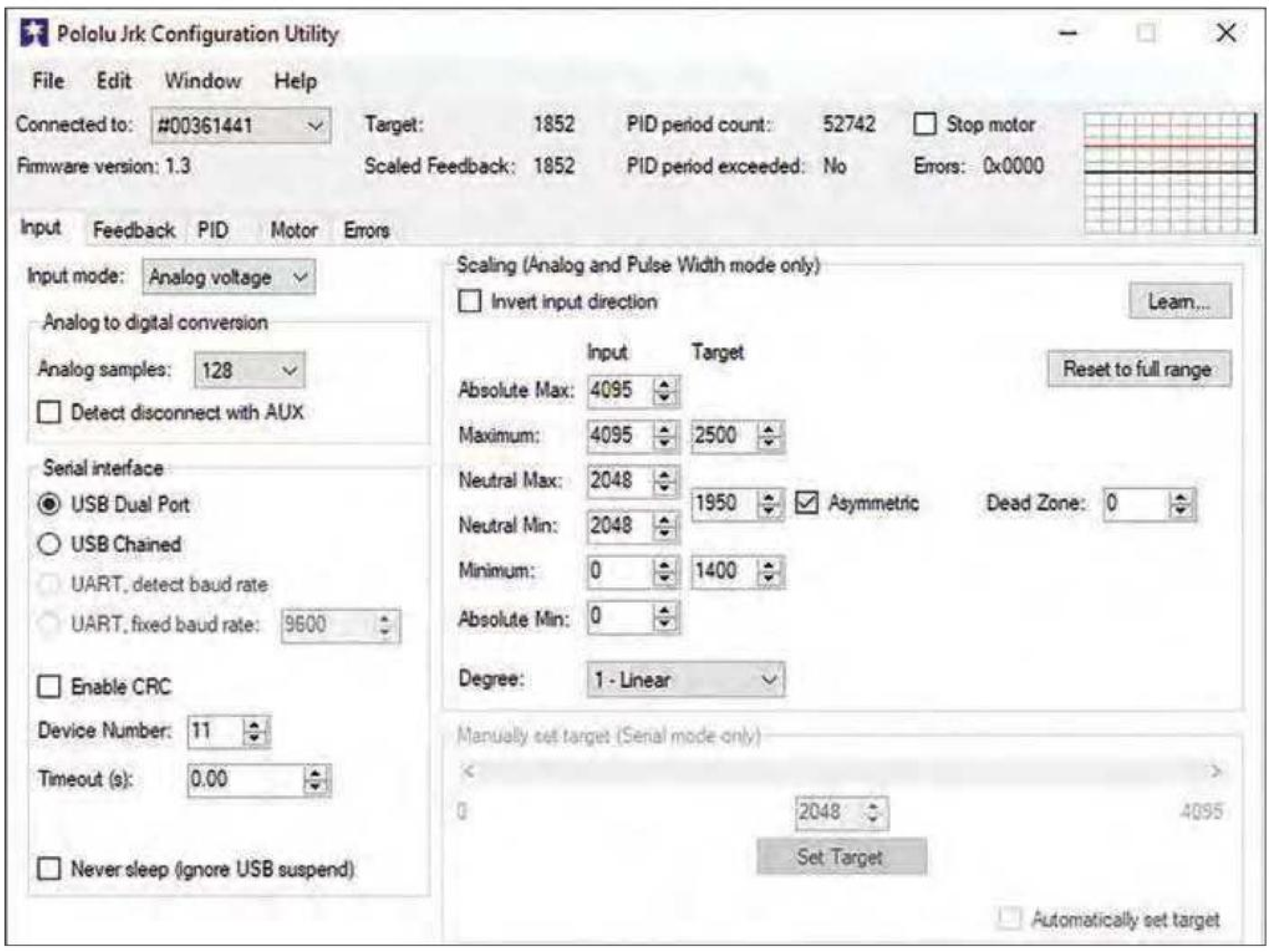


Fig.2. The connections for the Jrk 21v3 – a regulated 5V supply is available from multiple pins to power control and feedback pots. (Courtesy Pololu)



Connected to: #00361441
Firmware version: 1.3
Target: 1852
Scaled Feedback: 1852
PID period count: 52742
PID period exceeded: No
☐ Stop motor
Errors: 0x0000

Input mode: Analog voltage

Analog to digital conversion
Analog samples: 128
☐ Detect disconnect with AUX

Serial interface
● USB Dual Port
○ USB Chained
○ UART, detect baud rate
○ UART, fixed baud rate: 9600

☐ Enable CRC
Device Number: 11
Timeout (s): 0.00
☐ Never sleep (ignore USB suspend)

Scaling (Analog and Pulse Width mode only)
☐ Invert input direction

	Input	Target
Absolute Max:	4095	
Maximum:	4095	2500
Neutral Max:	2048	1950
Neutral Min:	2048	
Minimum:	0	1400
Absolute Min:	0	

☑ Asymmetric
Dead Zone: 0
Degree: 1 - Linear
2048
☐ Automatically set target

Fig.3. The *Input* tab. Note here that the *Analog voltage* input has been selected and that the *Target* has been reduced from a full range of 0-4095 to 1400-2500, so limiting the stroke of the actuator to suit the application. Visible near the top are the *Target* and *Scaled Feedback* values – here they are identical, indicating that the actuator has stopped at exactly the requested extension.

- 0-5V analogue control; eg, via a manual potentiometer.

Here, we will be using the 0-5V analogue control. The all-important feedback can be via the following two means:

- A 0-5V analogue signal
- Tachometer (speed) up to 2MHz.

Alternatively, the system can be set to have no feedback – that is, use open-loop control. We will be using the 0-5V feedback signal derived from the pot inside the linear actuator.

Above, I mentioned software. Using the USB connection to a PC (connection is via a USB Mini B connection – no cable provided), the following motor parameters can be altered:

- PID tuning
- Max current
- Max duty cycle
- Max acceleration
- Error response
- Input learning for analogue and RC control.

These may all mean little at this stage, so let's paint a word picture of what these settings can achieve. Say you were pretty excited by the picture in last month's issue, showing the TV that can rise out of a cabinet at your command. Using just a toggle switch to operate the linear actuator and its internal limit switches to turn it off at each end of its travel, you will have the following outcome. When the switch is operated, the TV will start rising with a jerk as power is applied to the motor. It will then rise at a speed determined by the supply voltage and actuator speed specification, before it reaches full height and trips the internal switch, stopping abruptly and probably shaking the whole assembly. On the way down it will probably travel a bit faster, making an even bigger jerk as it stops at the limit of its travel. OK, it does the job but hardly an elegant solution.

Now let's add the Jrk 21V3 controller. This time, the actuator speed increases progressively, starting almost imperceptibly and then gradually rising in speed. The maximum speed of the actuator can be pre-set – for example, to minimise noise, you can run it at a maximum speed of only 30% full speed. The point at which the actuator stops rising can also be set (that is, the actuator doesn't need to hit the limit switch) and as the actuator reaches that pre-set point, it can be programmed to progressively slow until it slides to a gentle halt. And that stopping point can be set and achieved with millimetre accuracy.

On the way back down, all these parameters can again be set, but this time taking into account the weight of the TV that will be hastening the retraction process. (In other words, you can have different settings for 'up' and 'down'.)

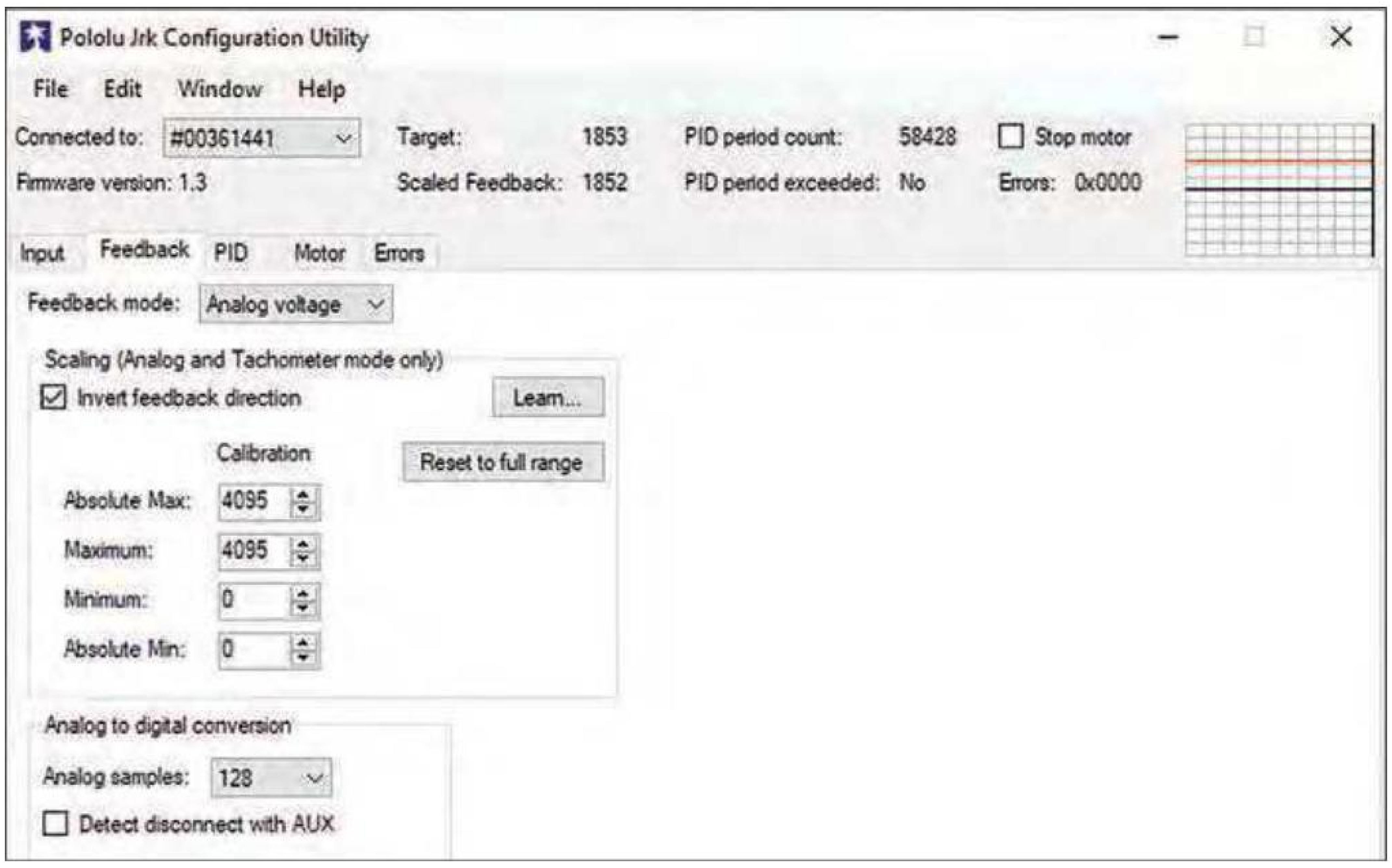
Now you can start to get a feel for what this controller can do with a linear actuator. And start to see the non-trivial nature of the programming involved, but which is built into the Pololu software – in particular, building your own, unconditionally stable PID controller is not straight forward.

Connections

As bought, the board will probably come with two loose 2-pin terminal blocks and a male header strip. These can be easily soldered to the board (this is not done at the factory in case you want to fit angled headers or different terminal blocks).

The terminal blocks are for power supply and the two motor connections. In addition, we are going to require connections for the feedback signal from the actuator, and the analogue control signal to set the position we want the linear actuator to achieve. (In our case, we'll use a simple pot to provide the control signal.)

Therefore, we will need regulated 5V outputs and grounds for the extremities of the two pot connections – these are available on the board and are well



Connected to: #00361441
Firmware version: 1.3
Target: 1853
Scaled Feedback: 1852
PID period count: 58428
PID period exceeded: No
☐ Stop motor
Errors: 0x0000

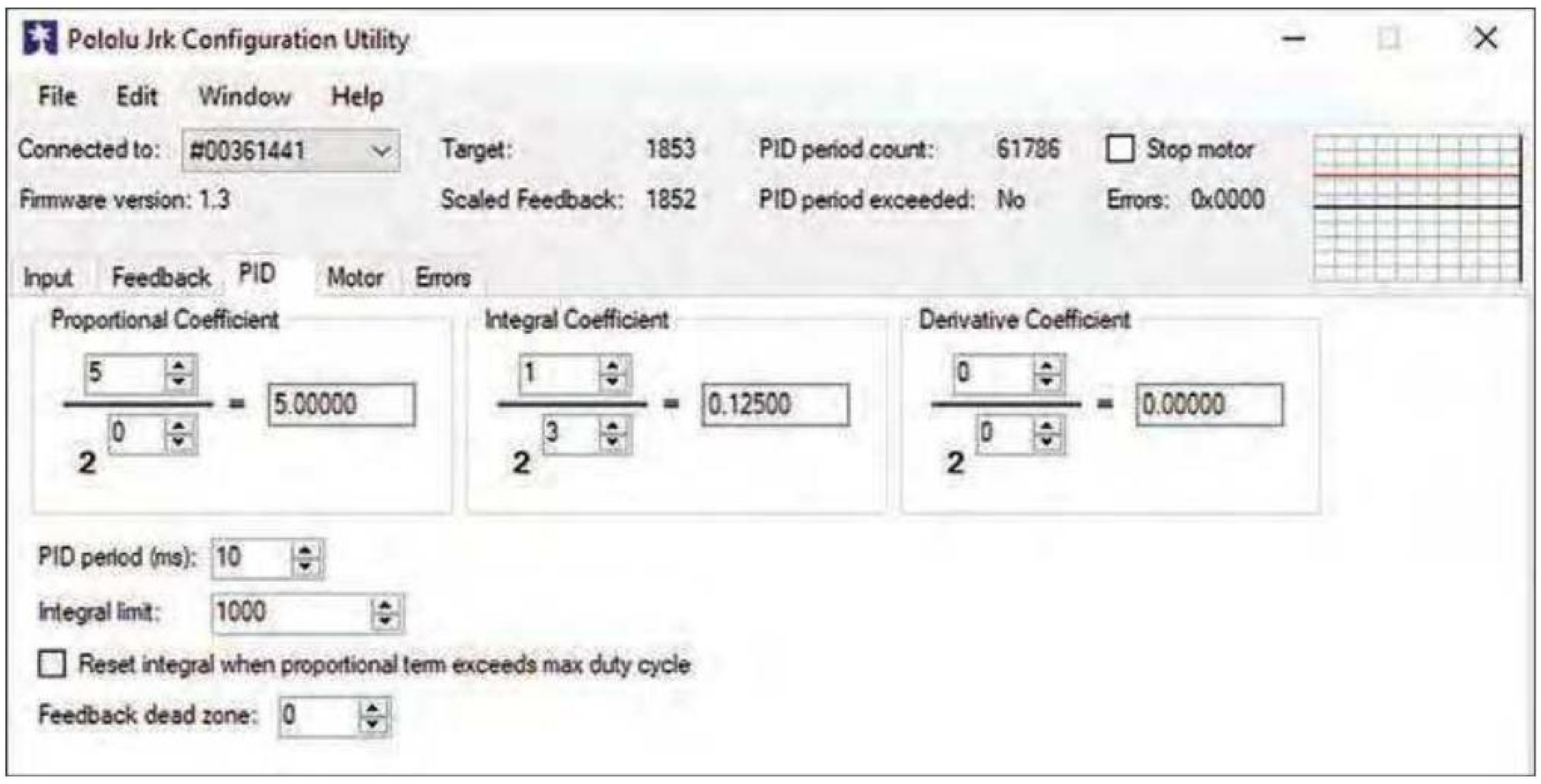
Feedback mode: Analog voltage

Scaling (Analog and Tachometer mode only)
☑ Invert feedback direction

	Calibration
Absolute Max:	4095
Maximum:	4095
Minimum:	0
Absolute Min:	0

Analog to digital conversion
Analog samples: 128
☐ Detect disconnect with AUX

Fig.4. The *Feedback* tab – *Analog voltage* has been selected as the feedback type, and because the feedback signal was working in the opposite direction to the *Input* direction, *Invert feedback direction* has been ticked.



Connected to: #00361441
Firmware version: 1.3
Target: 1853
Scaled Feedback: 1852
PID period count: 61786
PID period exceeded: No
☐ Stop motor
Errors: 0x0000

Proportional Coefficient: $\frac{5}{2^{0}} = 5.00000$

Integral Coefficient: $\frac{1}{2^{3}} = 0.12500$

Derivative Coefficient: $\frac{0}{2^{0}} = 0.00000$

PID period (ms): 10
Integral limit: 1000
☐ Reset integral when proportional term exceeds max duty cycle
Feedback dead zone: 0

Fig.5. The *PID* tab – the P, I and D parameters can all be altered. Note the unusual way in which the data is input – either as a fraction with the denominator multiplied by the adjacent numeral (unless you put in zero, whereupon it defaults to 1), or direct-entered as the coefficient. Playing with these settings gives enormous control over the behaviour of the system.

labelled. (Incidentally, a very good 55-page manual is available for the Jrk 21V3 – it's worth looking at before buying, as well as when building your board into your application.) The feedback signal from the actuator connects to the FB pin, while – not so obviously – the control input connects to the RX pin.

The board is protected against reverse polarity, over-load and over-temperature – so it should be difficult to kill it when making these connections. However, always turn off power first and check the wiring before switching power back on.

Software

The software is available from Pololu and is best accessed by clicking on the link in the pdf manual. There is a large section in the manual on installing the software, but with Windows 10 Pro I just followed the on-screen prompts and had no difficulties.

Testing

Do your initial testing with the actuator sitting on the bench, not connected to the device that you wish to mechanically move.

With the Jrk 21V3 plugged into the PC, click on the *Connected to* drop-down box and you should be able to select your device. Select the Input tab and then choose *Analog voltage* as the input mode. Ensure that as you turn the input pot, the *Target* number alters. You should also see a number associated with *Scaled Feedback* – but at this stage this won't change since the actuator isn't yet moving. So, if everything is connected, why isn't the actuator moving when the input pot is turned? It's because the PID settings are all still at zero. (PID – proportional, integral, derivative – is a control loop system that allows very effective control.)

Move to the *PID* tab and start by setting P to 20 – leave the other figures at zero at this stage. (After any calibration change, press *Apply settings to this device* to upload to the module.) Now with P at 20, when you turn the input pot, the actuator should move, slowing abruptly when it gets to the position you've selected. Now alter P to 5, and you should see that the actuator more progressively comes to a stop at the setpoint. To get the 'last little bit' of movement accurately to the setpoint, increase I (say to 0.125). You can now check how accurately the actuator is positioning itself at the setpoint – compare the difference between the *Target* and *Scaled Feedback* numbers. It's not hard to program the PID settings to achieve identical numbers – that is, the actuator has moved to precisely the correct point.

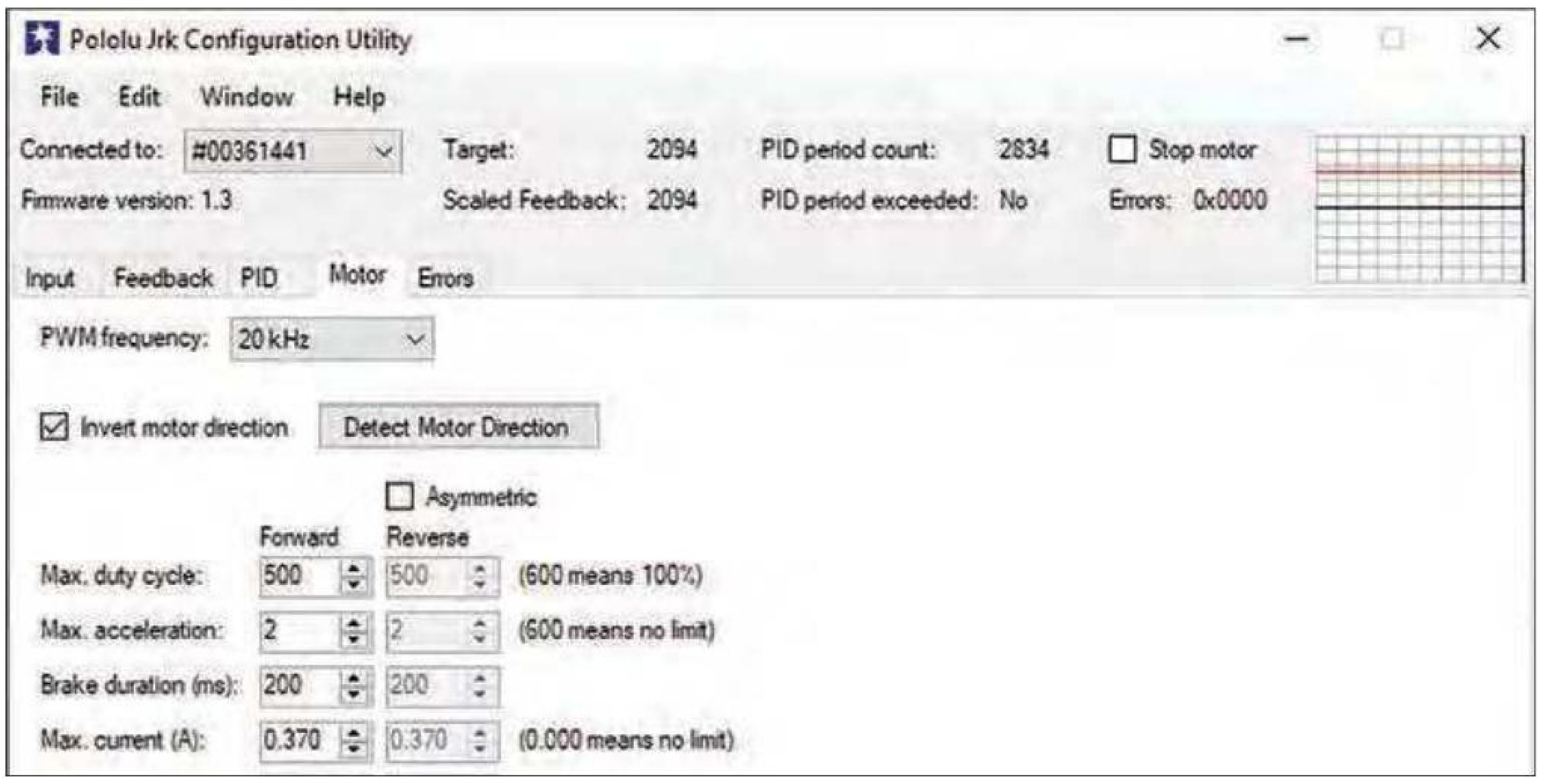
If the system seems to work nothing like the description in the above paragraph, you may have the Input and Feedback pots working in opposite directions. This is easily fixed by ticking the *Invert* box in either the *Input* or *Feedback* tabs (don't invert both or you'll be back to where you were before.)

If the actuator is being used across its full stroke, the inbuilt limit switches will come into play. That is, rather than the actuator slowing progressively, it will hit the limit switch and so stop abruptly. To prevent this occurring, you can reduce the target range of the Input pot. For example, rather than the range being 0 to 4095, change the *Target* to a maximum of 2500 and the minimum to 1400. This will then cause the actuator to work over a smaller stroke range.

So, now we have the actuator slowing progressively as it reaches the setpoint, but it still starts its movement with a jerk. Go to the *Motor* tab and place a small number (eg, 2) in the *Max. acceleration* box. Now when you turn the knob, the actuator will progressively gather speed. In the same tab we can change the maximum speed that the actuator reaches – this is specified by *Max. duty cycle*, where a count of 600 means 100%. One thing that is not obvious in this tab is the meaning of 'Brake duration'. In this application, it refers to the delay time if you turn the pot from one direction immediately to the other.

When setting up the PID parameters, it is worth opening the *Plots* tab. This window can then be dragged to one side and enlarged. The *Plots* tab allows you to graph a range of variables including error, motor duty cycle, target and feedback. The graph will quickly show if you have control overshoots or undershoots. It's also fascinating to watch as the system progressively reduces the error, the motor duty cycle smoothly reducing as the actuator draws closer to the correct stopping point.

Once the actuator is working correctly on the bench, install the actuator in the mechanical system it is going to control. Then, as the actuator is working under real world loads, some settings will probably need to be tweaked in the Jrk 21v3.

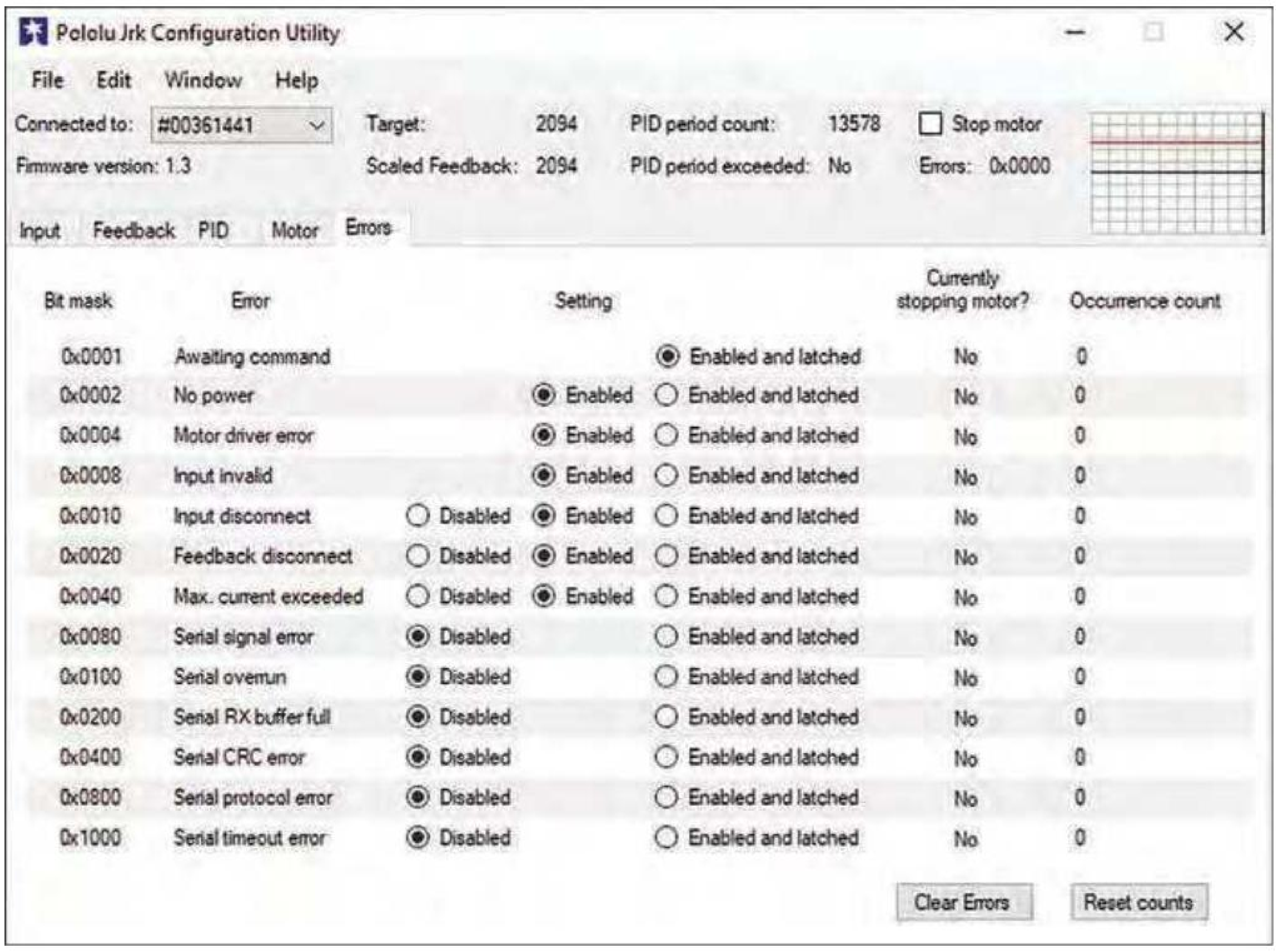


Connected to: #00361441
Firmware version: 1.3
Target: 2094
Scaled Feedback: 2094
PID period count: 2834
PID period exceeded: No
☐ Stop motor
Errors: 0x0000

PWM frequency: 20 kHz
☑ Invert motor direction
☐ Asymmetric

	Forward	Reverse	
Max. duty cycle:	500	500	(600 means 100%)
Max. acceleration:	2	2	(600 means no limit)
Brake duration (ms):	200	200	
Max. current (A):	0.370	0.370	(0.000 means no limit)

Fig.6. The *Motor* tab – here maximum speed, maximum acceleration and brake durations can all be set. These allow the system to be set up so that the actuator smoothly gathers speed and operates at a maximum speed that suits the requirements of the mechanical system. Current can also be limited – the system then specifies a motor duty cycle that causes this current value to not be exceeded.


Pololu Jrk Configuration Utility

File Edit Window Help

Connected to: #00361441 Target: 2094 PID period count: 13578 ☐ Stop motor

Firmware version: 1.3 Scaled Feedback: 2094 PID period exceeded: No Errors: 0x0000

Input Feedback PID Motor Errors

Bit mask	Error	Setting			Currently stopping motor?	Occurrence count
0x0001	Awaiting command			● Enabled and latched	No	0
0x0002	No power		● Enabled	○ Enabled and latched	No	0
0x0004	Motor driver error		● Enabled	○ Enabled and latched	No	0
0x0008	Input invalid		● Enabled	○ Enabled and latched	No	0
0x0010	Input disconnect	○ Disabled	● Enabled	○ Enabled and latched	No	0
0x0020	Feedback disconnect	○ Disabled	● Enabled	○ Enabled and latched	No	0
0x0040	Max. current exceeded	○ Disabled	● Enabled	○ Enabled and latched	No	0
0x0080	Serial signal error	● Disabled		○ Enabled and latched	No	0
0x0100	Serial overrun	● Disabled		○ Enabled and latched	No	0
0x0200	Serial RX buffer full	● Disabled		○ Enabled and latched	No	0
0x0400	Serial CRC error	● Disabled		○ Enabled and latched	No	0
0x0800	Serial protocol error	● Disabled		○ Enabled and latched	No	0
0x1000	Serial timeout error	● Disabled		○ Enabled and latched	No	0

Fig.7. The *Error* tab – a wide range of fault conditions can be monitored. They can each be *Enabled* or *Enabled and latched*, the latter stops the motor until a new command is received.

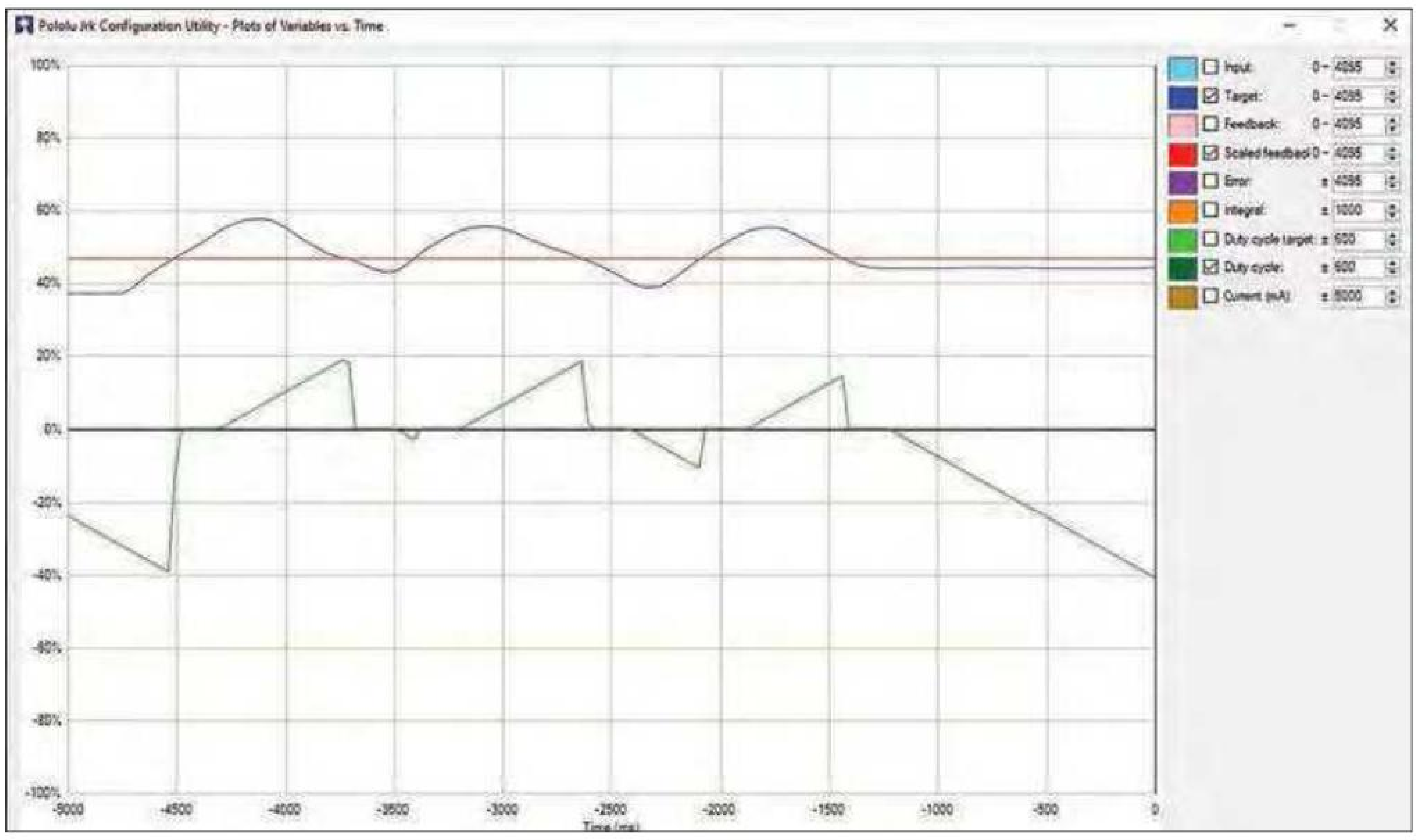


Fig.8. The Plots tab – this tab graphs in real time the selected parameters. Here *Target*, *Scaled feedback* and motor *Duty cycle* have been graphed. Note that what is shown above is *not* a good representation of what you normally see – here the input pot has been rapidly turned back and forth so that major changes could be seen over the maximum five-second window. Normally a step change in the input is followed by the feedback and target lines gradually coming together.

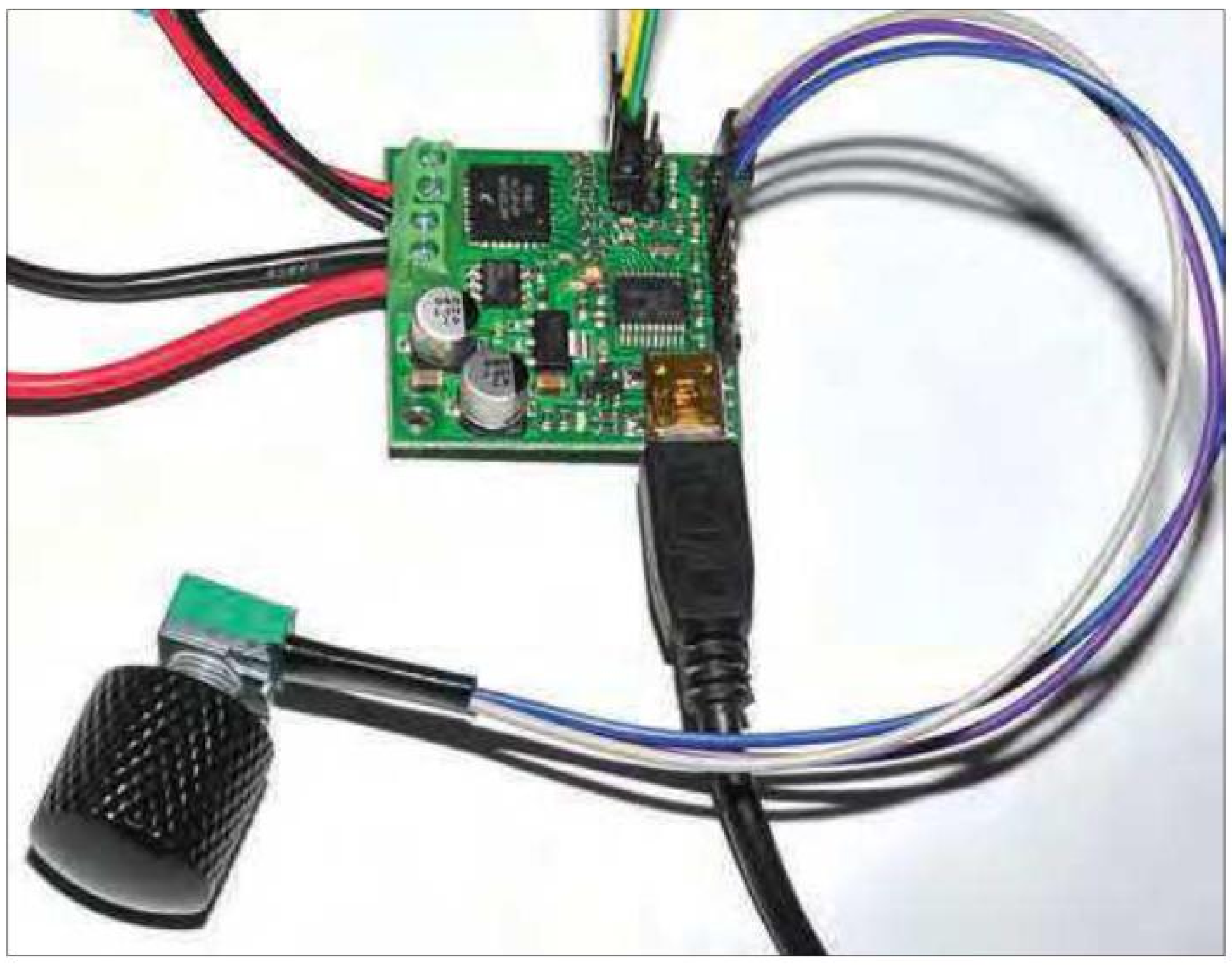


Fig.9. The Jrk 21v3 connected to a pot for the input (foreground). The green, yellow and white connections are to the feedback pot on the actuator. The red and black wires are for power and ground and the actuator motor connections. Here the Jrk 21v3 is connected to a PC via the USB cable for programming. As can be seen, to operate a linear actuator requires minimal connections.

Multi-switch position input

Rather than using a pot, it's easy to organise a rotary switch to give a variety of pre-set actuator positions. For example, in a racing car where an aerodynamic rear wing may need to be driver-adjusted in angle to take into account different track or fuel load conditions, a pot would be too fiddly to use. Instead, a 4-position rotary switch can be fitted – see Fig.10. In this approach, each pole of the switch is connected to the wiper of a 10kΩ, 10-turn, trim-pot wired across regulated 5V and ground. The voltage available on the wiper of each trim-pot can be set by turning the trim-pot – and thus the position of the actuator at each switch position can be adjusted. With a linear actuator controlling wing angle, four wing angles can then easily be selected under racing conditions. A similar 'pre-sets' approach could be taken if controlling house curtain openings, how far down a blind is to extend – and so on.

Conclusion

In the two parts in this series we've covered operating a linear actuator with the simplest and cheapest of approaches – just a toggle switch – right through to using a sophisticated programmable controller. (How sophisticated? In fact, in this article we've not covered every available feature of the Jrk 21V3 – there's simply not space to do so.) With the price of linear actuators having fallen so dramatically over the last few years, there's no excuse not to automate a whole variety of systems that require movement. Have fun doing so – and we'd love to see some of your projects using these actuators.

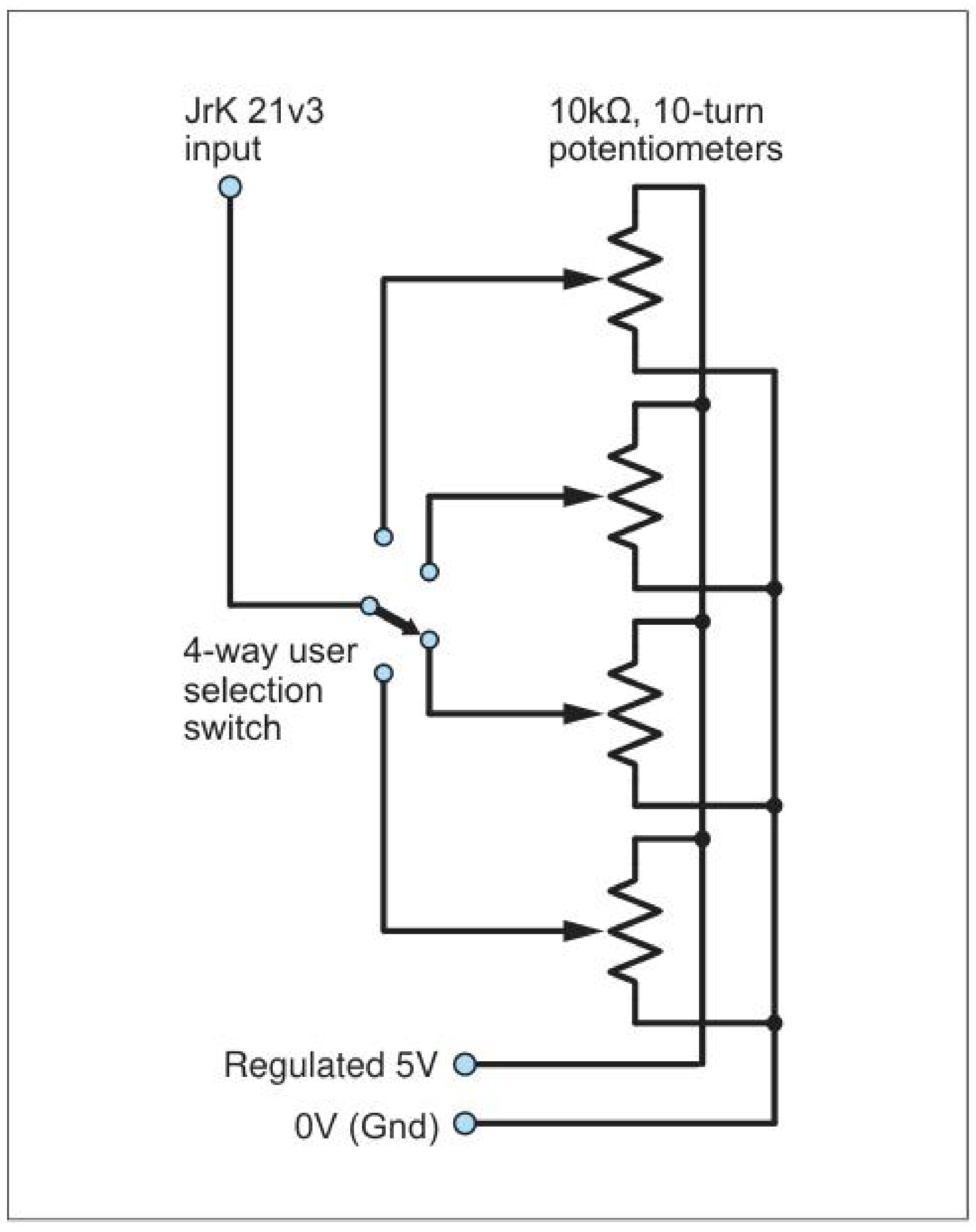


Fig.10. Here a multi-position switch has been used with four trim-pots to give four pre-set positions for the linear actuator. The position of each pre-set can be adjusted by rotating the relevant trim-pot.

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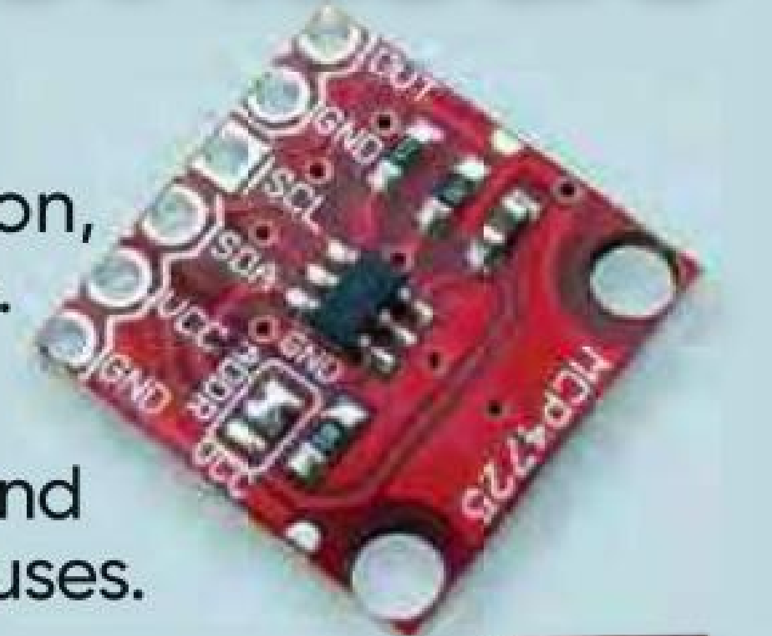


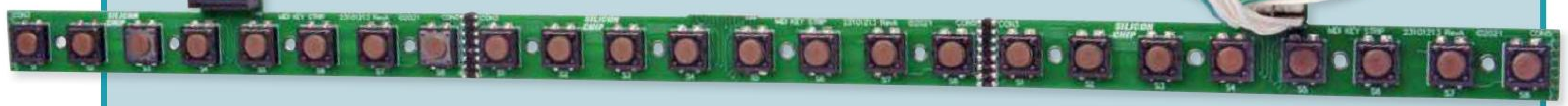
Multi-Purpose Battery Manager
Our Battery Manager will not just monitor what's going on but also take action, such as connecting and disconnecting loads based on battery charge state.

Simple MIDI Music Keyboard
This MIDI Keyboard is a follow-up to our 64-key MIDI Matrix. It is similarly flexible and offers a way to easily make music, although it can be repurposed for many other uses.

USB Power Delivery Chargers
Next month, we take a look at some low-cost modules that have appeared recently to take advantage of the dramatic growth in USB capability, especially in the area of power delivery.

Nano Pong
Our Nano Pong game is modern and retro at the same time; it replaces the 70 discrete logic chips in the original with a single chip that costs about £1!

KickStart – Exploring microcontroller digital-to-analogue conversion
This ninth instalment of KickStart explores ways of adding (and improving) analogue output capability from a wide range of popular microcontrollers.



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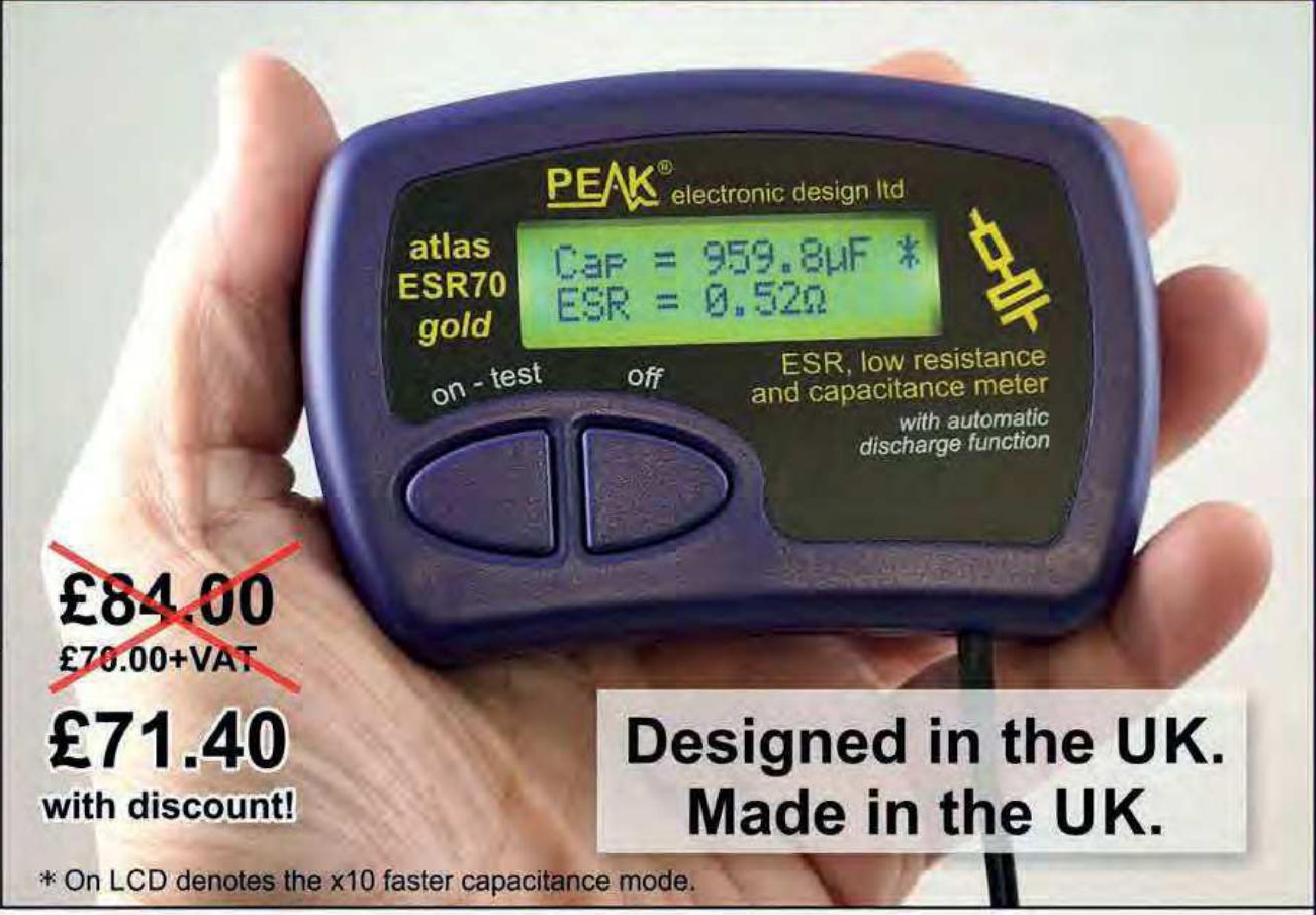

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